Smart Magnetic Drilling Fluid With In-Situ Rheological Controllability Using Fe3O4 Nanoparticles

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Abstract

Engineering a drilling fluid tailored to meet specific downhole and environmental demands with tunable rheological properties can revolutionize the drilling industry. This study investigates magnetically controllable, water-based drilling fluid systems containing custom-made (CM) iron oxide (Fe3O4) magnetic nanoparticles (NP). These could potentially offer in-situ control of the drilling fluid viscosity and yield stress, under the application of an external magnetic field.

CM Fe3O4 NP were synthesized by the co-precipitation method. NP were added to the base fluid at two different concentrations (0.5 and 1.0 wt%). The magnetorheological properties were analyzed via a strain-controlled rheometer equipped with a magnetic field source in parallel-plate geometry giving a range of magnetic flux densities of up to 1 Tesla (T). The rheological behavior of the produced fluids was examined at room temperature of 25°C as a function of volume fraction, shear rate and magnetic field strength.

Transmission electron microscopy (TEM) analysis revealed that the NP was spherical with mean diameter of 6-8 nm, while the X-ray diffraction (XRD) pattern revealed peaks corresponding to pure crystallites of magnetite (Fe3O4) with no impurities. Superconducting quantum interference device (SQUID) analysis proved that the prepared NP displayed superparamagnetic behavior. Magnetorheological measurements of the nanofluids indicated increase in the yield stress of up to +75% upon exposure to a magnetic field of 0.1 T, while larger changes of up to +609% were observed for higher concentrations of NP with intensities up to 0.7 T. The viscosity of the nano fluids monotonically increased under the presence of a magnetic field at all shear rates. The original rheological profile of the developed fluids was recovered upon removal of the magnetic field with an average deviation of +20% from the initial value, reflecting the disintegration of particle chains because of random movements due to Brownian forces.

Results highlight the potential for the development of multifunctional smart fluids that are greener and economical with tailor-made properties that can reversibly modify their rheological characteristics. Their unique ability to withstand a rapid increase in the viscosity and yield stress in the presence of an external magnetic field could enable drillers to formulate drilling fluid systems with instantaneous responses to continuously changing drilling environment, leading to enhanced well control and contributing to decreased non-productive time and costs.