Multifunctional Nano Additives for High-Performance Drilling Fluids

An Experimental Investigation for High-Temperature Applications

by

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Extended Abstract

The quest for energy in the 21st century has driven the oil, gas, and geothermal industries to explore greater depths, where extreme temperatures pose unprecedented challenges to conventional drilling technologies. In this high-stakes arena, water-based drilling fluids (WBDFs) have long been the preferred choice over non-aqueous drilling fluids (NADFs) due to their cost-effectiveness, environmental friendliness, and superior cooling properties. However, as wellbore temperatures go beyond 149°C, these fluids often falter, suffering from thermal degradation, viscosity loss, and excessive fluid invasion into formations. At the heart of this technological crucible are high-performance drilling fluids (HPDFs)—formulations engineered with nanoparticles that can withstand and perform in such harsh conditions.

The advent of nanomaterials in drilling fluid technology marks a paradigm shift, offering solutions to problems that have vexed engineers for decades. Nanoparticles, by virtue of their minuscule size and colossal surface area-to-volume ratio, interact with drilling fluids at a molecular level, bestowing properties that were once thought unattainable, especially in high-temperature regimes. The integration of nanoparticles into WBDFs is not merely an incremental improvement but a transformative leap. When dispersed in water-based muds, they form stable colloidal suspensions that dramatically enhance rheological stability, reduce fluid loss, mitigate shale swelling, and even improve lubricity—all without compromising the inherent benefits of WBDFs. Notably, nanomaterials are extensively researched as a multifunctional additive for WBDFs. However, to maximize the benefits and ensure the safe and effective application of the HPDFs, the optimal selection of nanomaterials, dosage, and compatibility with other additives present in the formulations still needs consideration. Therefore, the current work focuses on applying various nanomaterials. The objectives of the thesis work are as follows:

i. To address the aqueous dispersibility of commercial silica nanoparticles with surface modification and evaluate the performance in a water-based drilling fluid formulation.
ii. To synthesize cost-effective biogenic copper oxide nanoparticles and investigate their effects on lubricity and filtration performance.
iii. To investigate the role of different morphologies of zinc oxide nanomaterials and their size distributions on the performance of a water-based drilling fluid formulation.
iv. To upscale plastic waste to graphene nanosheets and evaluate their efficacy in water-based drilling fluids.
v. To modify and stabilize carbon nanotubes in polymeric dispersions for application in water-based drilling fluids.

Chapter 1 introduces the foundation for the research by clearly defining the problem, purpose, research questions, significance, and structure of the thesis. Also, this chapter provides a thorough review of the literature, offering a critical analysis of existing knowledge and identifying gaps that the current research aims to fill. It establishes a solid theoretical framework for the study, ensuring that the research is grounded in a comprehensive understanding of the topic. This chapter justifies the relevance and significance of the study within the context of existing research.

Chapter 2 establishes the experimental framework for the study, detailing how the research questions will be answered through systematic investigation and testing. It outlines the methodology used in the study, starting with the synthesis and modification of nanoparticles ensuring compatibility with drilling fluids. It then describes the analytical characterization of these nanoparticles to determine their physical and chemical properties. The chapter continues with the preparation of nanoparticle-infused drilling fluids, detailing the steps for dispersing nanoparticles and adding necessary additives for uniform and stable formulations. Finally, it covers the performance evaluation of these formulations, including tests for rheology, filtration, lubricity, and thermal aging to assess their suitability for high-temperature drilling conditions.

Chapter 3 investigates the use of silane-coated silica nanoparticles as additives to enhance the rheology and filtration control in WBDFs. It details the synthesis and coating process of the nanoparticles, followed by rheological and filtration tests at various concentrations. The results show significant improvements in viscosity and reduced degradation after thermal aging, along with a notable reduction in filtrate volume, demonstrating the effectiveness of these nanoparticles for high-temperature drilling applications.

Chapter 4 investigates the use of biogenic copper oxide nanoparticles (CuO NPs) synthesized from *Colocasia esculenta* leaf extract to enhance the lubricity, filtration, and rheological performance of drilling fluids. It demonstrates significant improvements in lubricity and filtration, as well as thermal stability under high-temperature conditions, showcasing the potential of these environmentally friendly nanoparticles for efficient and sustainable drilling operations.

Chapter 5 investigates the influence of morphological variations and dispersion stability of Zinc Oxide (ZnO) nanoparticles on the properties of HPDFs. Through synthesizing different ZnO nanostructures, namely Nano-pencils and Nano-flowers, and evaluating their performance in HPDFs via rheological and filtration tests, the study highlights the significant impact of nanostructure morphology and size distribution on fluid properties. Additionally, it provides insights into optimizing dispersion stability and pH conditions for enhanced HPDF performance, contributing valuable knowledge to nanoparticle-based drilling fluid design strategies.

Chapter 6 explores the utilization of graphene nanosheets (GNs) synthesized from plastic waste as additives in HPDFs. Through comprehensive characterization and experimental analysis, the chapter demonstrates the efficacy of GNs in enhancing rheological properties, thermal stability, and filtration control of water-based drilling fluids. The findings suggest that plastic-derived GNs can serve as eco-friendly additives, effectively improving drilling fluid performance and offering a sustainable solution to plastic waste while enhancing operations in high-temperature wells.

Chapter 7 investigates the efficacy of modified multi-walled carbon nanotubes (mMWCNTs) as additives in HPDFs for high-temperature conditions. Through tailored modifications to enhance dispersion and stability, the study comprehensively evaluates the performance of these mMWCNTs using material characterization, rheological analysis, stability assessments, and filtration performance evaluations. Results demonstrate significant improvements in filtration losses and rheological profile, validating the practical applicability of mMWCNTs for enhancing drilling fluid performance in high-temperature drilling operations.

Chapter 8 serves as the conclusion and offers future recommendations based on the findings and insights gained from the preceding chapters. It summarizes the key findings and contributions of each study, highlighting the implications for the field of drilling fluids. Additionally, it provides suggestions for future research directions and practical applications, aiming to guide further advancements in HPDF technologies for high-temperature drilling environments.

Nanomaterial	**Concentration in HPDFs (wt%)**	**Efficacy as Nano-additive**			
		Filtrate Reducer	**Rheology Modifier**	**Lubricity Improver**	**Thermal Stabilizer**
Silane-coated Silica Nanoparticles	0.200 – 0.400	Yes	Yes	-	Yes
Biogenic Copper Oxide Nanoparticles	0.100 – 1.000	Yes	No	Yes	Yes
Zinc Oxide Nano-Pencils	0.100 – 1.000	Yes	Yes	-	Yes
Zinc Oxide Nano-Flowers	0.100 – 1.000	Yes	Yes	-	Yes
Plastic Waste-upcycled Graphene Nanosheets	0.050 – 0.440	Yes	Yes	-	Yes
Modified Multiwalled Carbon Nanotubes	0.025 – 0.100	Yes	Yes	-	Yes