SURFACE MODIFICATION OF POLYETHYLENE GLYCOL-NANO SILICA USING SDS TO IMPROVE RHEOLOGICAL AND FILTRATION PROPERTIES OF WATER-BASED MUD

ISMAIL KATUN MOHAMUD

UNIVERSITI TEKNOLOGI MALAYSIA

SURFACE MODIFICATION OF POLYETHYLENE GLYCOL-NANO SILICA USING SDS TO IMPROVE RHEOLOGICAL AND FILTRATION PROPERTIES OF WATER-BASED MUD

ISMAIL KATUN MOHAMUD

A proposal submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Petroleum Engineering

School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2022

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Mohd Nooral Anam Norddin, for encouragement, guidance, critics and friendship. I am very thankful for his guidance, advices and motivation. Without his continued support and interest, this thesis would not have been the same as presented here.

My fellow postgraduate student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

In this study, 5 concentrations of SDS are used to surface-modify nanocomposite of polyethylene glycol-based silica (PEG-SiO_2-SDS NC). The objectives of the study are to evaluate the influence of SDS concentration in the surface modification of PEG-SiO_2-SDS on the rheological properties (plastic viscosity (PV), yield point (YP), and gel strength) and filtration properties of water-based drilling fluid. The experiment was conducted into two stages. The first part is the synthesis of PEG-SiO2 NC then surface modifying it with 5 SDS concentrations of 1.5, 2.5, 3.5, 4.5, 5.5 vol%. The synthesized PEG-SiO_2-SDS NCs undergo characterizations such as FESEM, EDX and TEM in order to confirm the synthesis and modification processes are successful. The second part is to study the effect of the 5 NCs on rheological properties and filtration properties as an additive to water-based mud (WBM). PEG-SiO_2 NC was synthesized from Tetraethyl orthosilicate (TEOS), polyethylene glycol (PEG), Ethanol (EtOH), ammonium hydroxide (NH4OH), and deionized water. The sodium dodecyl sulfonate (SDS) surfactant was used to functionalize the synthesized PEG-SiO_2 NC via surface modification. The WBM materials are freshwater (320 ml), caustic soda (NaOH) (0.15 gm), and bentonite (25 gm). All the materials were used as obtained without purification. The experimental results revealed that after modifying SDS, the low pressure-low temperature (LPLT) and high pressure-high temperature (HPHT) filtration loss of PEG-SiO2 additives was improved before and after hot rolling of mud samples at 250 °F for 16 h. When compared to base mud, the modified 0.1 g of PEG-SiO_2 with 3.5 vol% of SDS reduced the LPLT and HPHT filtration loss of drilling fluid by 46.3% and 45.5%, respectively. Drilling fluid rheological parameters such as AV, PV, YP, and gelation were also improved by modifying PEG-SiO_2 with SDS. The optimal SDS concentration for the best rheological properties is 3.5 vol%. As a result, the use of PEG-SiO_2 with 3.5% SDS in water-based mud produced favourable results, reaffirming the feasibility of using them in successful drilling operations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

API	-	American Petroleum Institute
AV	-	Apparent Viscosity
EDX	-	Energy Dispersive X-ray
EtOH	-	Ethanol
FTIR	-	Fourier Transform Infrared Spectroscope
HPHT	-	High Pressure High Temperature
LPLT	-	Low Pressure Low Temperature
NC	-	Nanocomposite
NP	-	Nanoparticle
PEG	-	Polyethylene Glycol
PV	-	Plastic Viscosity
RPM	-	Revolution Per Minute
SDS	-	Sodium Dodecyl Sulfate
SiO_2	-	Silica/Silicon Dioxide
TEM	-	Transmission Electron Microscope
TEOS	-	Tetra Ethyl Ortho Silicate
TGA	-	Thermogravimetric Analysis
WBM	-	Water-Based Mud
YP	-	Yield Point

LIST OF SYMBOLS

Vb	-	Amount of barite needs to make the increment, cc
Vi	-	Initial mud volume, bbl
ρi	-	Initial mud density, ppg
ρf	-	Final mud density, ppg
ρb	-	Density of Barite (35.4 ppg)

LIST OF APPENDICES

APPENDIX	TITLE	PAGE

CHAPTER 1

INTRODUCTION

1.1 Background

Drilling fluids have progressed from simple combinations of water and clays to sophisticated organic and inorganic mixtures of drilling fluid addition items. Drilling fluids are a vital part of the drilling process; the drilling fluid's performance determines how successful a drilling operation is. In typical circumstances, drilling fluids account for up to one-fifth (15 to 18%) of the total cost of drilling well, but they can account for up to 40% of the total cost in catastrophic losses (Ragab and Noah 2014). As a result, the optimal choice of drilling fluid type and features is critical to reducing drilling time and costs, especially given the current global challenge of low crude oil prices (Amanullah and Al-Tahini 2009).

Drilling fluids are intended to perform a variety of functions, such as managing reservoir pressure, cleaning holes, reducing the damage of the formation, lubricating and cooling drill bits, and preserving the stability of the wellbore. These tasks may be accomplished by addressing drilling fluid characteristics such as PV, mud density, YP, gel strength, apparent viscosity (AV), lubricity, mud filtrate loss volume, and shale inhibition well. Furthermore, regardless of the kind of formation or operating conditions, these obligations must be carried out consistently throughout the operation. Failure to follow any of these steps can result in serious drilling issues such as clogged pipes, reduced circulation, excessive torque and drag, formation damage, inadequate hole cleaning, and wellbore instability when conditions change (Abduo et al. 2016).

The rheological and filtration characteristics of the drilling fluid are two critical criteria that govern drilling operations. Polymers are used in drilling fluids to improve their rheological and filtration properties, and they are used to drill in difficult reactive-shale formations, high-pressure high-temperature (HPHT) wells, and saline environments (Smith et al. 2018; Caenn, Darley, and Gray 2017). As the depth of the hole increases, heat resistance becomes a vital component for polymer behavior under extreme temperatures (Smith et al. 2018; Mao et al. 2015). At high temperatures, the chains and branches of polymer break, causing viscosity degradation, a decrease in penetration rate, and a reduction in hole cleaning effectiveness (Boyou et al. 2019; Hakim et al. 2018; Aftab et al. 2016; Aftab, Ismail, and Ibupoto 2017; Jain, Mahto, and Mahto 2016). As a result, enhancing polymer heat resistance is a crucial research topic.

Once at the surface facilities, the cuttings must be removed from the system to avoid recirculation by using a low-gel-strength fluid and allowing the cuttings to settle (Egenti 2014). Drilling workers have previously depended on observation and expertise to determine the lifting ability of drilling fluids by raising either the flow rate or effective viscosity of the fluid to overcome ineffective cuttings removals, such as thick muds and high annulus velocities (Werner, Myrseth, and Saasen 2017). While increasing the viscosity or flow rate of the mud increases the cleaning action beneath the bit, it decreases the penetration rate (Polipropilena et al. 2015).

Nanotechnology has grown in popularity in the petroleum industry in recent years, particularly in the field of drilling fluid (Abdo et al. 2014; Xu et al. 2018). Some inorganic nano-materials, such as nano-silica, were used to seal pore throats, additives in drilling fluids to improve their qualities, and fissures in shale formations, forming a thin and compacted mud cake and significantly reducing pore pressure transfer (Cai et al. 2012; Akhtarmanesh, Shahrabi, and Atashnezhad 2013). However, due to their strong self-agglomeration tendency, they cannot completely solve the problems of wellbore instability (Elochukwu, Gholami, and Sham Dol 2017; Aftab, Ismail, and Ibupoto 2017). This has a major impact on the dispersion stability of WBM systems containing macro- or micro-sized particles.

Polyethylene glycol (PEG), a water-soluble alkaline oxide copolymer, is a good shale inhibiting agent in WBM and has effectively replaced older polyglycerols (Yuxiu et al. 2016). When employed in WBMs, it has been shown to be particularly successful in intercalating within the formation's clay matrix to limit filtrate loss, hold drilled cuttings together, and improve wellbore stability (William et al. 2014) created a WBM with PEG and found that the developed PEG-based drilling fluid system performs well in terms of shale inhibition and mud rheological qualities. As a result, it improved wellbore stability by suspending and lifting drilled cuttings to the surface. However, despite the technical efficiency, cost-effectiveness, and environmental acceptability of using PEG to formulate conventional WBM, it has a problem with thermal stability in high-temperature applications, which can cause a reduction in rheological property performance, thereby reducing cuttings transport efficiency (Aston and Elliott 1994)

Sodium dodecyl sulfonate (SDS) is a surfactant with an amphiphilic polar head and non-polar tail that allows it to self-associate in solution. Because of its low cost and ability to prevent particle oxidation and separation, SDS is the most commonly used and desired surfactant. It can also boost the hydrophilicity of PEG and help to stabilize the charge of SiO2 solution.

A water-based nanomud must comprise chemical additive particles of nanoscale dimensions (1 m=10^9 nm). Unlike its micro-sized parent particles, nanoparticles have a high surface area to volume ratio and supply additional charges to the mud, as well as minuscule sizes with great sensitivity and excellent particle dispersion. As a result, they are highly charged particles. Furthermore, they are classed as cationic or anionic nanoparticles based on the ion (atom) types on their surface. As a result, a small number of them can play important roles and execute several activities in water-based drilling mud.(Salih, Elshehabi, and Bilgesu 2017)

With the investigation of tight oil and gas reservoirs, nanoparticles in drilling fluid became more popular. Because shale deposits have narrow pore throats, it is difficult to create an impenetrable filter cake. As a result, the use of nanoparticles in drilling fluids in such applications was discovered to be effective in generating an impermeable filter cake around the wellbore wall and sealing micro cracks (Hoelscher et al. 2012)(Riley et al. 2012). Silica (SiO_2 NPs) is one of the most commonly employed NPs in drilling fluid due to its well-established chemistry that can be easily changed to minimize fluid interactions with formation fluids (Wilson 2012). Several studies were conducted to examine the influence of SiO_2 NPs on various base drilling fluids under various situations. Total, it was established that adding SiO_2 NPs to bentonite water-based fluid improved filtering properties and reduced overall fluid yield stress. Adding SiO_2 NPs to calcium-bentonite base fluid, on the other hand, resulted in a decrease in filter cake efficiency. Under HPHT testing settings, the rheological behavior of SiO_2 NPs in mineral oil base fluid revealed that fluid viscosity increases with increasing pressure and decreases with decreasing temperature. When compared to the base fluid and SiO2 NPs, Fe_2O_3 NPs improved filtration characteristics (Mahmoud et al. 2016). Other research on iron-based NPs found that they increased filtration while not influencing rheological qualities in oil base fluid. However, in the case of bentonite water-based drilling fluid, iron-based NPs demonstrated a minor improvement in rheological parameters, particularly yield stress (Al-Saba et al. 2018) theme.

1.2 Problem Statement

As a result, poorly constructed mud causes a variety of mud-related issues such as shale swelling, stuck pipe, bit balling, torque & drag, formation caving/sloughing, surge and swab pressures, reservoir damage, mud circulation loss, insufficient mud hydraulic system, and so on. All of these issues are directly tied to the drilling mud's rheological, filtration, and hydraulic qualities, which are directly related to the mud's flocculation level. As a result, high flocculation is recognized as one of the most damaging phenomena in water-based mud, failing the mud design and increasing drilling challenges. This has a high filtering volume, yield point, plastic viscosity, gel strength, mud cake thickness, and low mud pumpability as a result (Salih and Bilgesu 2017).

PEG-SiO_2 NP alone is facing agglomeration (less stable) problem and need to be treated via surface modification continuing on the success of PEG-SiO_2-SDS NP that was reported by (Blkoor et al. 2022).

However, the impacts of varying the SDS composition on the modified PEG-SiO_2 NC material in WBMs towards optimum stability thus optimum in reducing agglomeration have not been determined. Moreover, the effect of SDS composition on rheology, filtrate loss control, filter cake thickness and permeability, pH, and density have also not been determined, for both LPLT and HPHT.

1.3 Research Objectives

The objectives of the research are:

(a) To synthesize and characterize PEG-SiO_2 NC material.

(b) To treat (by surface modification) and characterize (for stability) the said PEG-SiO_2 NC with various volume% (concentration) of SDS

(c) To verify the effect of various concentrations of SDS in PEG-SiO_2-SDS NC on the rheological and filtration properties of WBM under LPLT and HPHT conditions.

(d) To find the optimum concentration of SDS in stabilizing the PEG-SiO_2-SDS NC as well as the optimum in the rheological and filtration properties in WBM.

1.4 Scope of the study

(a) Synthesizing PEG-SiO_2 NC and modifying it with 5 SDS concentration (1.5, 2.5, 3.5, 4.5, 5.5 vol%)

(b) Characterizing of the 5 synthesized PEG-SiO_2-SDS NC with different techniques such as (FESEM), EDX and (TEM) in order to confirm the synthesis and modification processes.

(c) Comparing the effect of the 5 synthesized PEG-SiO_2-SDS NC in WBM on rheological properties (Density, Plastic viscosity, Yield point, Gel strength, and Apparent viscosity) for both low temperature and after hot rolling

(d) Comparing the effect of the 5 synthesized PEG-SiO_2-SDS NC in WBM on filtration properties for both LPLT and HPHT conditions

1.5 Significance of the study

(a) This study's findings could lead to a new method and opportunities for enhancing rheological and filtration properties

(b) The findings of this research could also give the optimal concentration of SDS to enhance rheological and filtration qualities.

(c) Other areas of the oil and gas business that nanoparticles can be used in include EOR, workover, and completion tasks.

REFERENCES

Abdo, J, R Zaier, E Hassan, H Al-Sharji, and A Al-Shabibi. 2014. "ZnO–Clay Nanocomposites for Enhance Drilling at HTHP Conditions." *Surface and Interface Analysis* 46 (10–11): 970–74.

Abduo, M I, A S Dahab, Hesham Abuseda, Abdulaziz M AbdulAziz, and M S Elhossieny. 2016. "Comparative Study of Using Water-Based Mud Containing Multiwall Carbon Nanotubes versus Oil-Based Mud in HPHT Fields." *Egyptian Journal of Petroleum* 25 (4): 459–64.

Adari, Rishi B, Stefan Miska, Ergun Kuru, Peter Bern, and Arild Saasen. 2000. "Selecting Drilling Fluid Properties and Flow Rates for Effective Hole Cleaning in High-Angle and Horizontal Wells." In *SPE Annual Technical Conference and Exhibition*. OnePetro.

Aftab, A, A R Ismail, and Z H Ibupoto. 2017. "Enhancing the Rheological Properties and Shale Inhibition Behavior of Water-Based Mud Using Nanosilica, Multi-Walled Carbon Nanotube, and Graphene Nanoplatelet." *Egyptian Journal of Petroleum* 26 (2): 291–99.

Aftab, A, A R Ismail, S Khokhar, and Zafar Hussain Ibupoto. 2016. "Novel Zinc Oxide Nanoparticles Deposited Acrylamide Composite Used for Enhancing the Performance of Water-Based Drilling Fluids at Elevated Temperature Conditions." *Journal of Petroleum Science and Engineering* 146: 1142–57.

Akhtarmanesh, S, M J Ameri Shahrabi, and A Atashnezhad. 2013. "Improvement of Wellbore Stability in Shale Using Nanoparticles." *Journal of Petroleum Science and Engineering* 112: 290–95.

Al-Saba, M. T., A. Al Fadhli, A. Marafi, A. Hussain, F. Bander, and M. F. Al Dushaishi. 2018. "Application of Nanoparticles in Improving Rheological Properties of Water Based Drilling Fluids." *Society of Petroleum Engineers - SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition 2018, SATS 2018*, 1–10. https://doi.org/10.2118/192239-ms.

Al-Zubaidi, Nada S, Asawer A Alwasiti, and Dena Mahmood. 2017. "A Comparison of Nano Bentonite and Some Nano Chemical Additives to Improve Drilling Fluid Using Local Clay and Commercial Bentonites." *Egyptian Journal of Petroleum*

26 (3): 811–18.

Amanullah, Md, Mohammad K Al-Arfaj, and Ziad Al-Abdullatif. 2011. "Preliminary Test Results of Nano-Based Drilling Fluids for Oil and Gas Field Application." In *SPE/IADC Drilling Conference and Exhibition*. OnePetro.

Amanullah, Md, and Ashraf M Al-Tahini. 2009. "Nano-Technology-Its Significance in Smart Fluid Development for Oil and Gas Field Application." In *SPE Saudi Arabia Section Technical Symposium*. OnePetro.

Anoop, Kanjirakat, Reza Sadr, Mohammed Al-Jubouri, and Mahmood Amani. 2014. "Rheology of Mineral Oil-SiO2 Nanofluids at High Pressure and High Temperatures." *International Journal of Thermal Sciences* 77: 108–15. https://doi.org/10.1016/j.ijthermalsci.2013.10.016.

Aston, M.S., and G.P. Elliott. 1994. "Water-Based Glycol Drilling Muds: Shale Inhibition Mechanisms," October. https://doi.org/10.2118/28818-MS.

Azar, Jamal J, and G Robello Samuel. 2007. *Drilling Engineering*. PennWell books.

Blkoor, Shafeeg O., M.N.A. Mohd Norddin, Issham Ismail, Jeffrey O. Oseh, Augustine Agi, Afeez O. Gbadamosi, Nnanna O. Okoli, and Ifeanyichukwu M. Onyejekwe. 2022. "Amphipathic Anionic Surfactant Modified Hydrophilic Polyethylene Glycol-Nanosilica Composite as Effective Viscosifier and Filtration Control Agent for Water-Based Drilling Muds." *Arabian Journal of Chemistry*, 103741. https://doi.org/10.1016/j.arabjc.2022.103741.

Bourgoyne Jr, Adam T, Keith K Millheim, Martin E Chenevert, and Farrile S Young Jr. 1986. "Applied Drilling Engineering. Volume 2."

Boyou, Natalie Vanessa, Issham Ismail, Wan Rosli Wan Sulaiman, Amin Sharifi Haddad, Norhafizuddin Husein, Heah Thin Hui, and Kathigesu Nadaraja. 2019. "Experimental Investigation of Hole Cleaning in Directional Drilling by Using Nano-Enhanced Water-Based Drilling Fluids." *Journal of Petroleum Science and Engineering* 176: 220–31.

Busahmin, Bashir, Nawaf H Saeid, Gamal Alusta, and El-Said M M Zahran. 2017. "Review on Hole Cleaning for Horizontal Wells." *ARPN J. Eng. Appl. Sci* 12 (16): 4697–4708.

Caenn, Ryen, H C H Darley, and George R Gray. 2017. "Chapter 5-Water-Dispersible Polymers." *Composition and Properties of Drilling and Completion Fluids*, 135–50.

Caenn, Ryen, Henry C H Darley, and George R Gray. 2011. *Composition and*

Properties of Drilling and Completion Fluids. Gulf professional publishing.

Cai, Jihua, Martin E Chenevert, Mukul M Sharma, and Jim Friedheim. 2012. "Decreasing Water Invasion into Atoka Shale Using Nonmodified Silica Nanoparticles." *SPE Drilling & Completion* 27 (01): 103–12.

Cho, H, S N Shah, and S O Osisanya. 2002. "A Three-Segment Hydraulic Model for Cuttings Transport in Coiled Tubing Horizontal and Deviated Drilling." *Journal of Canadian Petroleum Technology* 41 (06).

Choi, Hoon, and I. Wei Chen. 2003. "Surface-Modified Silica Colloid for Diagnostic Imaging." *Journal of Colloid and Interface Science* 258 (2): 435–37. https://doi.org/10.1016/S0021-9797(02)00130-3.

Contreras, Oscar, Geir Hareland, Maen Husein, Runar Nygaard, and Mortadha Alsaba. 2014. "Wellbore Strengthening in Sandstones by Means of Nanoparticle-Based Drilling Fluids." In *SPE Deepwater Drilling and Completions Conference*. OnePetro.

Dhiman, Annudeep Singh. 2012. "Rheological Properties & Corrosion Characteristics of Drilling Mud Additives." *M. Sc, Dalhouse University*.

Duan, Mingqin, Stefan Miska, Mengjiao Yu, Nicholas Takach, Ramadan Ahmed, and John Hallman. 2010. "Experimental Study and Modeling of Cuttings Transport Using Foam with Drillpipe Rotation." *SPE Drilling & Completion* 25 (03): 352–62.

Dyke, Kate Van. 2000. *Drilling Fluids*. Petroleum Extension Service, Continuing & Extended Education, the University ….

Egenti, Nkechinyere Barbara. 2014. "Understanding Drill-Cuttings Transportation in Deviated and Horizontal Wells." In *SPE Nigeria Annual International Conference and Exhibition*. OnePetro.

El-Diasty, Abdelrahman Ibrahim, and Adel M Ragab. 2013. "Applications of Nanotechnology in the Oil & Gas Industry: Latest Trends Worldwide & Future Challenges in Egypt." In *North Africa Technical Conference and Exhibition*. OnePetro.

Elochukwu, Henry, Raoof Gholami, and Sharul Sham Dol. 2017. "An Approach to Improve the Cuttings Carrying Capacity of Nanosilica Based Muds." *Journal of Petroleum Science and Engineering* 152 (April): 309–16. https://doi.org/10.1016/J.PETROL.2017.03.008.

FAROOQI, FARZOK. 2018. "Improving the Cuttings Transport and Hole Cleaning

In," no. January.

Ghanbari, Saeed, Ezatallah Kazemzadeh, Mohammad Soleymani, and Abbas Naderifar. 2016. "A Facile Method for Synthesis and Dispersion of Silica Nanoparticles in Water-Based Drilling Fluid." *Colloid and Polymer Science* 294 (2): 381–88. https://doi.org/10.1007/s00396-015-3794-2.

Haaland, Ellen, Geir Pettersen, and Oystein B Tuntland. 1976. "Testing of Iron Oxides as Weight Materials for Drilling Muds." *Paper SPE* 6218.

Hakim, Hadyan, Allan Katende, Farad Sagala, Issham Ismail, and Hussein Nsamba. 2018. "Performance of Polyethylene and Polypropylene Beads towards Drill Cuttings Transportation in Horizontal Wellbore." *Journal of Petroleum Science and Engineering* 165: 962–69.

Hanson, P M, T K Trigg, G Rachal, and M Zamora. 1990. "Investigation of Barite Sag in Weighted Drilling Fluids in Highly Deviated Wells." In *SPE Annual Technical Conference and Exhibition*. OnePetro.

Hoelscher, Katherine Price, Guido De Stefano, Meghan Riley, and Steve Young. 2012. "Application of Nanotechnology in Drilling Fluids." In *SPE International Oilfield Nanotechnology Conference and Exhibition*. OnePetro.

Ilyas, Suhaib Umer, Rajashekhar Pendyala, and Narahari Marneni. 2014. "Preparation, Sedimentation, and Agglomeration of Nanofluids." *Chemical Engineering & Technology* 37 (12): 2011–21.

Jain, Rajat, Triveni K Mahto, and Vikas Mahto. 2016. "Rheological Investigations of Water Based Drilling Fluid System Developed Using Synthesized Nanocomposite." *Korea-Australia Rheology Journal* 28 (1): 55–65.

Jung, Youngsoo, Matthew Barry, Jung-kun Lee, Phuoc Tran, Yee Soong, Donald Martello, and Minking Chyu. 2011. "Jung 2011 (Conference)" v: 1–4.

Khodja, Mohamed, Malika Khodja-Saber, Jean Paul Canselier, Nathalie Cohaut, and Faïza Bergaya. 2010. "Drilling Fluid Technology: Performances and Environmental Considerations." *Products and Services; from R&D to Final Solutions*, 227–56.

Larsen, T I, A A Pilehvari, and J J Azar. 1997. "Development of a New Cuttings-Transport Model for High-Angle Wellbores Including Horizontal Wells." *SPE Drilling & Completion* 12 (02): 129–36.

Li, Long, Xubo Yuan, X Xu, S Li, and L Wang. 2013. "Vital Role of Nanotechnology and Nanomaterials in the Field of Oilfield Chemistry." In *IPTC 2013:*

International Petroleum Technology Conference, cp-350-00005. European Association of Geoscientists & Engineers.

Mahmoud, Omar, Hisham A Nasr-El-Din, Zisis Vryzas, and Vassilios C Kelessidis. 2016. “Nanoparticle-Based Drilling Fluids for Minimizing Formation Damage in HP/HT Applications.” In *SPE International Conference and Exhibition on Formation Damage Control*. Society of Petroleum Engineers.

Majid, Nor Fatin Fatihah, Allan Katende, Issham Ismail, Farad Sagala, Norshila Md Sharif, and Mohd Azizi Che Yunus. 2019. “A Comprehensive Investigation on the Performance of Durian Rind as a Lost Circulation Material in Water Based Drilling Mud.” *Petroleum* 5 (3): 285–94.

Mao, Hui, Zhengsong Qiu, Zhonghou Shen, and Weian Huang. 2015. “Hydrophobic Associated Polymer Based Silica Nanoparticles Composite with Core–Shell Structure as a Filtrate Reducer for Drilling Fluid at Utra-High Temperature.” *Journal of Petroleum Science and Engineering* 129: 1–14.

McNerlin, Brandon, and N Oakey. 2011. “Barite Sag Occurrence and Resolution during Angolan Completion Operations.” In *SPE Annual Technical Conference and Exhibition*. OnePetro.

Menzel, Dieter. 1973. “A New Weighting Material for Drilling Fluids Based on Synthetic Iron Oxide.” In *Fall Meeting of the Society of Petroleum Engineers of AIME*. OnePetro.

Mijić, Petar, Nediljka Gaurina-Međimurec, Borivoje Pašić, and Igor Medved. 2019. “The Influence of TiO2 and SiO2 Nanoparticles on Filtration Properties of Drilling Muds.” *Rudarsko-Geološko-Naftni Zbornik* 34 (4): 67–77.

Piroozian, Ali, Issham Ismail, Zulkefli Yaacob, Parham Babakhani, and Ahmad Shamsul Izwan Ismail. 2012. “Impact of Drilling Fluid Viscosity, Velocity and Hole Inclination on Cuttings Transport in Horizontal and Highly Deviated Wells.” *Journal of Petroleum Exploration and Production Technology* 2 (3): 149–56.

Polipropilena, Menggunakan Manik, M D U ONUOHA, I ISMAIL, A PIROOZIAN, N S MAMAT, and A S ISMAIL. 2015. “Improving the Cuttings Transport Performance of Water-Based Mud through the Use of Polypropylene Beads.” *Sains Malaysiana* 44 (4): 629–34.

Rafati, Roozbeh, Sean Robert Smith, Amin Sharifi Haddad, Rizky Novara, and Hossein Hamidi. 2018. “Effect of Nanoparticles on the Modifications of Drilling

Fluids Properties: A Review of Recent Advances." *Journal of Petroleum Science and Engineering* 161: 61–76.

Ragab, A M Salem, and Ahmed Noah. 2014. "Reduction of Formation Damage and Fluid Loss Using Nano-Sized Silica Drilling Fluids." *Petroleum Technology Development Journal* 2: 75–88.

Rana, D, and G H Neale. 2001. "The Intrinsic Binding Constant (" 300: 297–300.

Riley, Meghan, Emanuel Stamatakis, Steve Young, Katerine Price Hoelsher, Guido De Stefano, Lou Ji, Quan Guo, and Jim Friedheim. 2012. "Wellbore Stability in Unconventional Shale-the Design of a Nano-Particle Fluid." In *SPE Oil and Gas India Conference and Exhibition*. OnePetro.

Salih, A. H., and H. Bilgesu. 2017. "Investigation of Rheological and Filtration Properties of Water-Based Drilling Fluids Using Various Anionic Nanoparticles." *SPE Western Regional Meeting Proceedings* 2017-April: 837–57. https://doi.org/10.2118/185638-ms.

Salih, A. H., T. A. Elshehabi, and H. I. Bilgesu. 2016. "Impact of Nanomaterials on the Rheological and Filtration Properties of Water-Based Drilling Fluids." *SPE Eastern Regional Meeting* 2016-Janua. https://doi.org/10.2118/184067-MS.

Salih, A H, T A Elshehabi, and H I Bilgesu. 2017. "Impact of Nanomaterials on the Rheological and Filtration Properties of Water-Based Drilling Fluids, SPE Eastern Regional Meeting, Canton, Ohio, 2016, USA." *J. Petrol. Sci. Eng* 152: 309–16.

Shah, Subhash N, Narayan H Shanker, and Chinenye C Ogugbue. 2010. "Future Challenges of Drilling Fluids and Their Rheological Measurements." In *AADE Fluids Conference and Exhibition, Houston, Texas*. sn.

Si, Claire Chang Li. 2014. "Experimental Study on the Effect of Nano-Silica on Mud Density in Synthetic Based Mud."

Sifferman, Thomas R, George M Myers, Elard L Haden, and Harry A Wahl. 1974. "Drill Cutting Transport in Full Scale Vertical Annuli." *Journal of Petroleum Technology* 26 (11): 1295–1302.

Skebo, Jeanne E., Christin M. Grabinski, Amanda M. Schrand, John J. Schlager, and Saber M. Hussain. 2007. "Assessment of Metal Nanoparticle Agglomeration, Uptake, and Interaction Using High-Illuminating System." *International Journal of Toxicology* 26 (2): 135–41. https://doi.org/10.1080/10915810701226248.

Smith, Sean Robert, Roozbeh Rafati, Amin Sharifi Haddad, Ashleigh Cooper, and

Hossein Hamidi. 2018. "Application of Aluminium Oxide Nanoparticles to Enhance Rheological and Filtration Properties of Water Based Muds at HPHT Conditions." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 537: 361–71.

Srivatsa, Jayanth T, and Malgorzata Barbara Ziaja. 2011. "An Experimental Investigation on Use of Nanoparticles as Fluid Loss Additives in a Surfactant-Polymer Based Drilling Fluids." In *International Petroleum Technology Conference*. OnePetro.

Suliza Muhamad, Mimi, Mohd Razman Salim, and Woei-Jye Lau. 2015. "Surface Modification of SiO 2 Nanoparticles and Its Impact on the Properties of PES-Based Hollow Fiber Membrane." https://doi.org/10.1039/c5ra07527k.

Taraghikhah, S, M Kalhor Mohammadi, and K Tahmasbi Nowtaraki. 2015. "Multifunctional Nanoadditive in Water Based Drilling Fluid for Improving Shale Stability." In *International Petroleum Technology Conference*. OnePetro.

Walker, S, and J Li. 2000. "The Effects of Particle Size, Fluid Rheology, and Pipe Eccentricity on Cuttings Transport." In *SPE/ICOTA Coiled Tubing Roundtable*. OnePetro.

Werner, Benjamin, Velaug Myrseth, and Arild Saasen. 2017. "Viscoelastic Properties of Drilling Fluids and Their Influence on Cuttings Transport." *Journal of Petroleum Science and Engineering* 156: 845–51.

William, Jay Karen Maria, Swaminathan Ponmani, Robello Samuel, R Nagarajan, and Jitendra S Sangwai. 2014. "Effect of CuO and ZnO Nanofluids in Xanthan Gum on Thermal, Electrical and High Pressure Rheology of Water-Based Drilling Fluids." *Journal of Petroleum Science and Engineering* 117: 15–27.

Wilson, Adam. 2012. "Nanoparticle Use in Drilling Fluids Can Effectively Reduce Permeability in Shale." *Journal of Petroleum Technology* 64 (11): 87–90.

Xie, Yanjun, Callum A.S. Hill, Zefang Xiao, Holger Militz, and Carsten Mai. 2010. "Silane Coupling Agents Used for Natural Fiber/Polymer Composites: A Review." *Composites Part A: Applied Science and Manufacturing* 41 (7): 806–19. https://doi.org/10.1016/j.compositesa.2010.03.005.

Xu, Jian-gen, Zheng-song Qiu, Xin Zhao, Han-yi Zhong, Gong-rang Li, and Wei-an Huang. 2018. "Synthesis and Characterization of Shale Stabilizer Based on Polyethylene Glycol Grafted Nano-Silica Composite in Water-Based Drilling Fluids." *Journal of Petroleum Science and Engineering* 163: 371–77.

Yuxiu, An, Jiang Guancheng, Qi Yourong, Huang Xianbin, and Shi He. 2016. "High-Performance Shale Plugging Agent Based on Chemically Modified Graphene." *Journal of Natural Gas Science and Engineering* 32: 347–55.

Zadravec, Damir, and Zdenko Krištafor. 2018. "Contribution to the Methodology of Determining the Optimum Mud Density-a Case Study from the Offshore Gas Condensate Field D in the Persian Gulf." *Rudarsko-Geološko-Naftni Zbornik* 33 (4).