Impact of Perlite on the Properties and Stability of Water-Based Mud in Elevated-Temperature Applications

Abdelmjeed Mohamed, Salem Basfar, Salaheldin Elkatatny,* and Badr Bageri

ABSTRACT: Barite settling is one of the common drilling fluid issues encountered while drilling deep wells. In this study, the effect of perlite on the properties and stability of water-based drilling fluid was investigated. Perlite is an inexpensive additive used in different industrial applications such as bricks, concrete, thermal insulators, sludge absorbents, fillers, tiles, ruminants, and poultry. Perlite additive was also introduced to the oil industry in drilling applications as an effective fluid loss control agent to reduce the drilling fluid invasion into the formations. Perlite was added to the drilling fluid in various concentrations, ranging between 0 and 3.0 lb/bbl. The sag test was performed to assess the drilling fluid’s stability under dynamic and static conditions at a temperature of 120/250 °F. Then, the impact of perlite on the properties of drilling fluid was assessed by measuring the density and pH at room temperature. While the rheological, viscoelastic, and filtration properties were evaluated at 250 °F. This study showed that an increase in perlite concentration, from 0 to 3 lb/bbl, slightly reduced the pH of the drilling fluid; however, all of the values were within the acceptable pH range (9−11). In contrast, this concentration of perlite had an immeasurable impact on drilling fluid density. Perlite enhanced the drilling fluid’s homogeneity and stability by reducing the dynamic and static sag factors, and 3.0 lb/bbl perlite was adequate to eliminate barite sag at a temperature up to 250 °F. Perlite was found to be effective in improving the rheological and viscoelastic properties. A significant enhancement of filtration properties was observed by the reduction in filtrate volume and filter cake thickness by 64 and 31%, respectively.

1. INTRODUCTION

Drilling fluids play a vital role in the success and total cost of drilling applications. Drilling fluids are introduced into the wellbore to serve many functions such as hole cleaning, controlling the well pressure, maintaining the wellbore stability by forming a filter cake on the wall of the well, and lubricating and cooling the drilling bit.2−4 Therefore, the drilling fluid is designed by choosing the appropriate additives to maintain its properties throughout drilling operations and fulfill these functions.5,6 Many parameters should be considered in mud design and additive selection such as lithology, temperature, pressure, drilling cost, and other encountered issues, such as lost circulation, wellbore stability, and well control issues.7,8 In the past decades, the increased demand for energy pushed the oil industry and geothermal industry toward deep and unconventional drilling to unlock the energy resources.9−11 Drilling in such environments increased the urge for special drilling fluid additives that can withstand the harsh conditions encountered downhole such as high temperatures and high pressures.7 The degradation of polymeric additives,12−15 flocculation and swelling of bentonite muds,16,17 and solids sag18,19 are different forms of drilling fluid instability induced by the high downhole temperature.

Solids sag, or barite sag, is the separation of solid particles from the liquid phase. Solids sag is experienced with weighted drilling fluids, where weighting agents are present in the drilling fluid formulation to increase the mud weight and suppress the high formation pressure.20−23 Many parameters contribute to the sagging phenomenon, such as drilling fluid properties, weighting agents, particle size, downhole conditions, time, pipe rotation, well inclination, and well geometry.24−26 The sagging phenomenon mechanism is that the solid particles separate from the liquid phase and start to accumulate downhole, causing the density of the drilling fluid column to vary with the depth (Figure 1). Consequently, the mud weight becomes less than the formation pressure in the upper parts of the drilled section, which may cause a severe well control issue.27,28 The solid particles, accumulated in the lower part of the well, increase the mud weight and equivalent circulating density (ECD). This

Received: October 4, 2020
Accepted: November 25, 2020
Published: December 7, 2020
increase may induce fractures in the formation leading to partial or total loss circulation, especially when the mud window is narrow.\textsuperscript{29,30} Moreover, these accumulated solids interfere with drilling and completion operations and cause pipe sticking.\textsuperscript{31–33} Many techniques were introduced in previous studies to mitigate the solids sag and other fluid stability issues. These methods can be classified into three main categories: modify or replace the weighting agent with more stable material or a combination of weight materials,\textsuperscript{5,6,26,34,35} add antisagging agents,\textsuperscript{20,36–41} and implement sound techniques for early detection of the sag phenomenon and prepare rig crew for such situations.\textsuperscript{33} Lab measurements of the sag tendency are conducted to evaluate the effectiveness of these methods, such as sag tests that rely on the real monitoring of mud density using sag cells, flow loops, and viscometers.\textsuperscript{27,31,36,42–45} Monitoring of fluid density can be achieved by direct measurements, nuclear magnetic resonance (NMR) and ultrasonic technique,\textsuperscript{25} and light scattering technique.\textsuperscript{36} Another sag detection method is to monitor the rheological and viscoelastic behaviors of drilling fluids.\textsuperscript{18,24,47–50}

Figure 1. Occurrence and complications of the solids sag phenomenon.

Figure 2. Experimental procedure.
Some of the proposed solutions to the sag issue have limitations or challenging to apply in real-field applications due to availability, cost, technical issues, or environmental concerns. Therefore, the need for more feasible and advanced solutions still exists. Perlite is an amorphous volcanic rock having a high water content. It has the ability to expand 6–17 times its volume when exposed to high temperatures. Perlite is used in different industrial applications such as bricks, concrete, thermal insulators, sludge absorbents, fillers, tiles, ruminants, and poultry. Perlite additive was also introduced to the oil industry in drilling applications as a fluid loss control agent to reduce the drilling fluid invasion into the formations. This study evaluates the effectiveness of perlite to enhance water-based mud’s properties and stability and solve the solids sag issue in elevated-temperature drilling applications. Perlite was added to the drilling fluid in various concentrations, and the sag tendency was evaluated using dynamic and static sag tests. The performance of the drilling mud, with and without perlite additive, was compared, considering the pH, density, rheological and viscoelastic behaviors, and filtration properties.

No previous studies were conducted to investigate the effect of perlite additive on the drilling fluid stability in elevated-temperature applications to the authors’ best knowledge. Therefore, this work’s novelty is that it evaluates and introduces a new solution to the solids sag issue using an inexpensive additive to safely and efficiently drill oil and gas wells.

2. MATERIAL AND METHODS

The impact of perlite additive on the properties and stability of drilling mud was investigated as follows:

- Perlite and barite powders were characterized by determining the elemental composition, particle size distribution, and morphology.
- Several drilling mud samples were prepared by varying the concentration of perlite (0−3.0 lb/bbl).
- The density and pH of the mud samples were measured at room temperature.
- The sag tendency was evaluated for all mud samples using static and dynamic sag tests.
- To verify the optimum perlite concentration, a complete evaluation was performed on the mud samples by measuring filtration, viscoelastic, and rheological properties.
- The mud sample’s performance with the optimum concentration was compared to the base drilling mud considering all measured properties. Figure 2 summarizes the experimental procedure followed in conducting this study.

2.1. Material Characterization. The elemental compositions of both perlite and barite were determined by a micro-X-ray fluorescence (micro-XRF) method. The particle size distribution analysis was performed on dry samples using the laser diffraction technique, while the morphologies of perlite and barite were studied using scanning electron microscopy (SEM).

2.2. Drilling Fluid Preparation. The base drilling fluid was prepared by mixing the drilling fluid additives following the formulation shown in Table 1. First, soda ash was added to the base fluid (water) to maintain water hardness. Defoamer was added to prevent foam formation, while potassium hydroxide was used to control the pH of mud. The mud viscosity was maintained using bentonite and xanthan gum polymer. Then, starch, regular polyanionic cellulose (PAC-R), and calcium carbonate were used to enhance the filtration properties of the mud. Potassium chloride was added as a clay stabilizer, and barite was used to increase the mud density. All of the additives were mixed at room temperature using a three-speed mixer. The order and time of the mixing process are described in Table 1. Following the same procedure, several drilling fluid samples were prepared by adding perlite in various concentrations (0−3.0 lb/bbl). Afterward, the impact of perlite on the mud properties was studied.

2.3. Sag Test. The effect of perlite on drilling fluid stability was studied by conducting a series of sag experiments, static and dynamic. An aging cell setup was used to perform the static sag test at 250 °F and 500 psi (Figure 3a). The maximum testing temperature was set at 250 °F due to the temperature limitation of the polymeric additives in the mud formulation, while the pressure was applied to prevent fluid evaporation. The inclination angle was varied from 0 to 45° to simulate vertical and inclined wells. The experiments were carried on for 24 h, and the sag tendency was measured for all samples using the densities of top and bottom fluids. The sag factor was calculated using eq 1. The higher the sag factor, the higher the sag tendency, while a sag factor ranging between 0.5 and 0.53 is considered acceptable.

\[
\text{sag factor} = \frac{\text{sag factor bottom density}}{\text{bottom density} + \text{top density}}
\]  

(1)

Dynamic sag tendency was measured at standard conditions (120 °F and atmospheric pressure) using the viscometer sag shoe test, VSST (Figure 3b). Experiments were conducted by running the viscometer at 100 RPM for 30 min. Two fluid samples (10 mL each) were taken from the collection well in the sag shoe before and after the test. The weight of both samples (W<sub>before</sub> and W<sub>after</sub>, in g), the dynamic sag tendency was calculated using eq 2. Stable fluids have a VSST equal to or less than one, while a VSST higher than one indicates solids sag.

\[
\text{VSST} = 0.834(W_{\text{after}} - W_{\text{before}})
\]  

(2)

2.4. Rheological and Viscoelastic Behaviors. The effect of perlite on the rheological behavior of the mud was evaluated by measuring the gel strength, plastic viscosity (PV), and yield point (YP). The experiments were conducted using an OFITE viscometer (model 130-77). The measurements were performed at 250 °F, and a pressure of 1000 psi was applied to prevent fluid
composition analysis (Figure 4), the barite sample mostly

viscoelastic behavior of the drilling mud samples was compared using filtration tests. Filtration tests were conducted at 250 °F and 300 psi differential pressure using a high-pressure, high-temperature filter press. The filtration was performed using a 10 μm ceramic filter disk, and the experiments were run for 30 min. The filtration performance of mud samples was compared using the filtrate volume and the thickness and weight of the formed filter cake. The experimental parameters of the filtration tests are summarized in Table 3.

3. RESULTS AND DISCUSSIONS

3.1. Material Characterization. From the elemental composition analysis (Figure 4), the barite sample mostly

Table 2. Experimental Conditions for Sag Tests

| parameter          | static sag | dynamic sag |
|--------------------|------------|-------------|
| fluid volume       | 190 cm³    | 170 cm³     |
| pressure           | 500 psi    | 14.73 psi   |
| temperature        | 250 °F     | 120 °F      |
| inclination        | vertical/inclined 45° |             |
| test duration      | 24 h       | 30 min      |

Figure 3. Sag test apparatus: (a) static and (b) dynamic. (Reprinted with permission from Elkatatny50 and Basfar et al.39)

Table 3. Experimental Conditions for Filtration Experiments

| parameter       | description         |
|-----------------|---------------------|
| mud volume      | 350 cm³             |
| temperature     | 250 °F              |
| differential pressure | 300 psi          |
| filtration time | 30 min              |
| filtration medium | 10 μm ceramic disk|

Figure 4. Elemental compositions of barite and perlite using micro-XRF.

evolution. The viscometer readings at 300 and 600 RPM were used to calculate the plastic viscosity and yield point, while the viscometer reading at 3 RPM was used to obtain the gel strength after 10 s, 10 min, and 30 min.

Then, an Anton Paar rheometer was used to study the viscoelastic behavior of the mud samples by conducting oscillatory tests. The oscillatory tests were performed at 250 °F and 1000 psi. First, the amplitude sweep test was run to obtain the linear viscoelastic range by running the rheometer at a fixed frequency (10 rad/s) and variable shear stress. A fresh sample was then used to conduct the frequency sweep test, where a constant strain value was applied, and the angular frequency was varied. The applied strain value should be taken from the linear viscoelastic range. The effect of perlite additive on the viscoelastic behavior of the drilling fluid was studied using the data obtained from the oscillatory test, loss modulus (\(G'\)), and storage modulus (\(G''\)).

2.5. Filtration Experiments. A series of filtration tests were performed to study the impact of perlite additive on water-based mud filtration properties. Filtration tests were conducted at 250 °F and 300 psi differential pressure using a high-pressure, high-temperature filter press. The filtration was performed using a 10 μm ceramic filter disk, and the experiments were run for 30 min. The filtration performance of mud samples was compared using the filtrate volume and the thickness and weight of the formed filter cake. The experimental parameters of the filtration tests are summarized in Table 3.

3.2. Sag Test. Several drilling fluid samples were prepared in the laboratory by varying the perlite concentration from 0 to 3.0 lb/bbl. After fluid preparation, the effect of perlite on drilling fluid density and pH was studied. The base drilling fluid, without perlite, showed a density of 14.7 ppg and a pH of 11.2. Figure 7 shows that the perlite slightly reduced the pH as the concentration increased to reach a minimum of 9.75 at 3.0 lb/bbl of perlite concentration. The reduction in pH can be attributed to the low pH value of perlite additive, compared with the base mud. Perlite typically has a pH value ranging between 6 and 8.60 However, this slight reduction in pH does not impact the drilling fluid performance because the pH value is still within the recommended pH range (9–11) according to oilfields’ drilling practices. Moreover, the pH can always be adjusted by adding small concentrations of pH control additives such as caustic soda, potassium hydroxide, and lime. In contrast, the impact of perlite on the drilling fluid density was immeasurable by laboratory equipment because the concentrations added to...
the drilling fluid samples were very low. All of the fluid samples had a density of 14.7 ppg (Figure 7).

The effect of perlite concentration on sag tendency at different conditions, static and dynamic, is shown in Figures 8 and 9. For static conditions, the sag tendency was measured at vertical and inclined (45°) conditions. The base drilling fluid, without perlite, exhibited a high sag tendency at both dynamic and static conditions. The static sag factor varied from 0.57 to 0.58 for vertical and inclined conditions, exceeding the acceptable sag factor range (0.50–0.53) as per field practices.5,6,44,49 The sag factor in inclined conditions was always greater than the sag factor in vertical conditions because the sag tendency is accelerated at inclined conditions.61 Similarly, the base fluid showed a high potential for dynamic solids sag with a high dynamic sag factor of 2.3, where it should be equal to or less than 1.0 for successful and safe drilling operations.42 Adding perlite to the drilling fluid improved fluid stability by reducing the sag tendency under both dynamic and static conditions. As perlite concentration was increased, the sag factor was reduced. Adding perlite with 3.0 lb/bbl concentration successfully brought the sag factor to the safe zone with static and dynamic sag factors around 0.5 and 0.2, respectively. Thus, solids sag is unlikely to occur under these conditions. The improvement in mud homogeneity and stability is attributed to the colloidal interactions between perlite particles and water. In clay minerals, the colloidal activities are highly dependent on specific surface and surface charge.3 Perlite has a high specific surface due to the platy shape of its particles (Figure 5b). Moreover, like smectite clays, perlite has the ability to absorb water, causing an expansion in the crystal lattice 6–17 times its volume.52 This swelling significantly increases the specific surface, thus increasing the colloidal activity and its impact on the mud properties.3

3.3. Rheological and Viscoelastic behaviors. The rheological and viscoelastic behaviors of the drilling fluid with
and without perlite (0 and 3.0 lb/bbl) were studied at 250 °F by measuring the rheological and viscoelastic properties. Such properties are gel strength, yield point, plastic viscosity, storage modulus, and loss modulus. Adding 3.0 lb/bbl perlite increased the yield point of the mud by 70%, from 24 to 41 lb/100 ft², while the plastic viscosity was slightly reduced from 18 to 16 cP (Figure 10a). The base drilling fluid exhibited an unstable gel structure at elevated-temperature conditions. The gel strength started with 13 lb/100 ft² after 10 s and decreased with time to reach 7 lb/100 ft² after 30 min of static gel time, confirming the sagging phenomenon (Figure 10b). Conversely, perlite improved the gel structure at elevated temperatures by forming

Figure 8. Impact of perlite additive on static sag tendency.

Figure 9. Impact of perlite additive on dynamic sag tendency.

Figure 10. Impact of perlite on rheological properties of drilling mud at 250 °F: (a) yield point and plastic viscosity and (b) gel strength.
a stronger gel with gel strengths of 21, 23, 25 lb/100 ft² after 10 s, 10 min, and 30 min, respectively. The improvement in gel strength and yield point is caused by an increase in colloidal activity induced by the perlite platelets swelled when exposed to water. This increase of yield point and gel strength indicates the enhancement in the mud capability to keep the solid particles in suspension and reduce the sag tendency at dynamic and static conditions, confirming the sag test results. Another advantage of using perlite with high-density mud is enhancing yield point to plastic viscosity ratio (YP/PV). Perlite additive increased the YP/PV significantly from 1.31 to 2.58 to fall within the recommended range as per drilling practices (1.5–3). This increase in YP/PV improves the hole cleaning efficiency, drilling fluid stability, wellbore hydraulics, and other important drilling parameters. Lower values of YP/PV would trigger stability issues such as solids sag, while higher values would cause mud flocculation and coagulation.

Figure 11 compares the viscoelastic behavior of 0 and 3.0 lb/bbl of perlite concentrations at 250 °F. The base mud sample below 2% strain exhibited a linear viscoelastic range where the loss modulus is less than the storage modulus. The mud in this range of strain behaves more like viscoelastic solids. After exceeding this range of strain, the gel started to break, and the mud behaved like liquids. In contrast, the sample with 3.0 lb/bbl perlite showed a broader linear viscoelastic range until the strain reached around 10%. Therefore, perlite increased the strength and stability of the gel structure, indicating a better suspension capability in static conditions. The rheological and viscoelastic behaviors support the sag tests' findings that perlite improves the homogeneity, stability, and suspension capability of the drilling fluid. This makes perlite a good additive to be used in elevated-temperature drilling applications. However, this work is a qualitative study to prove the effectiveness of perlite. More research studies should be performed to optimize the concentration and mixing procedure and extend the application for higher temperature conditions.

3.4. Filtration Performance. The impact of perlite on filtration performance was investigated at 250 °F and 300 psi differential pressure using an HPHT filter press apparatus. For the base drilling fluid sample, the filtrate volume was increasing rapidly until 15 min of filtration time to reach around 6 cm³; then, the fluid filtrate invasion started to cease with a total filtrate volume of 6.7 cm³. Conversely, perlite reduced the filtrate volume to 2.4 cm³ (by 64%), and the filter cake was built faster (Figure 12). Figure 13 shows the photographs and SEM images of the formed filter cake after the filtration experiments. Perlite particles formed a more compact filter cake, with a thickness of around 2.7 mm, while a 4 mm filter cake was formed with the base drilling fluid (0 lb/bbl perlite). This improvement in the filtration properties is attributed to the plugging mechanism due to the platy shape of perlite particles, as shown in the SEM images (Figure 5). The jagged edges of perlite particles interlocked the solid particles that, in turn, clogged the pore space of the filtration disk and filter cake, preventing further solid and fluid filtrate invasion. Moreover, the increase in mud properties caused by perlite can be another factor in enhancing filtration performance. As reported in a previous study, the fluid losses decrease significantly as the yield point increases. As shown in the SEM images in Figure 13, fewer vugs and pores were observed with the 3.0 lb/bbl perlite, indicating a less porosity and more compacted filter cake than the base fluid. The reduction in filtrate volume observed with perlite helps minimize the formation of damage induced by filtrate and solids invasion. Simultaneously, the thinner filter cake resulting from perlite addition decreases the possibility of differential sticking. Moreover, thinner filter cake makes the filter cake removal process easier, eliminating further complications to cementing and casing operations and minimizing the non-
productive time (NPT). The filtration results also support the findings of the previous study conducted by Bageri et al., studying the effect of perlite particles on the filtration properties.

4. SUMMARY AND CONCLUSIONS

In this study, perlite additive was added to the drilling fluid in various concentrations, 0.0−3.0 lb/bbl. The influence of perlite additive on water-based mud’s properties and stability was investigated at elevated temperatures (250 °F). Based on the obtained results, the following conclusions can be made:

- The base drilling fluid (0.0 lb/bbl perlite) exhibited poor stability with high static and dynamic sag factors. The value of static and dynamic sag factors exceeded the acceptable values (0.53 and 1.0), indicating the high potential of solids sag. While perlite enhanced the stability of the mud by reducing the static and dynamic sag factors, perlite at 3.0 lb/bbl concentration was enough to bring the sag factors to the acceptable range.

- Perlite slightly reduced the pH of the drilling fluid from 11.2 to 9.75; however, all of the values were still within the acceptable range of pH (9−11) according to the field practices. In contrast, adding this perlite concentration to the drilling fluid had an immeasurable impact on the mud density.

- Perlite enhanced the rheological behavior at 250 °F by increasing the yield point by 70%, while the plastic viscosity was slightly decreased by 11%, increasing the yield point to plastic viscosity ratio (YP/PV) from 1.31 to 2.58. This increase brought the YP/PV to the recommended range, 1.5−3.0, as per the industry practices, improving the drilling fluid stability and hole cleaning efficiency.

- Perlite significantly improved the filtration performance of mud. The filtrate volume was reduced by 64%, and a thinner and more compacted filter cake was formed (30% less thickness than the base fluid). This improvement in the filtration performance minimizes the formation of damage induced by drilling fluid invasion into producing formations.

- Perlite was proved effective in improving the drilling fluid performance at elevated temperatures; however, this work is a qualitative study rather than a quantitative study. Thus, preliminary research should be performed to determine the optimum perlite concentration before field implementation to account for any changes in drilling fluid formulation and downhole conditions.

■ AUTHOR INFORMATION

Corresponding Author

Salaheldin Elkatatny − Department of Petroleum Engineering, College of Petroleum & Geosciences, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

Email: elkatatny@kfupm.edu.sa

Authors

Abdelmjeed Mohamed − Department of Petroleum Engineering, College of Petroleum & Geosciences, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

Salem Basfar − Department of Petroleum Engineering, College of Petroleum & Geosciences, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

Badr Bageri − Department of Petroleum Engineering, College of Petroleum & Geosciences, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

Complete contact information is available at: https://pubs.acs.org/10.1021/acsomega.0c04853

Notes

The authors declare no competing financial interest.

■ REFERENCES

1. Kayaci, K. The Use of Perlite as Flux in the Production of Porcelain Stoneware Tiles. Bol. Soc. Esp. Ceram. Vidrio 2020, 8, 1−8.
2. Hossain, M. E.; Al-Majed, A. A. Fundamentals of Sustainable Drilling Engineering; Scivener Publishing LLC: Beverly, MA, 2015.
3. Caenn, R.; Darley, H. C. H.; Gray, G. R. Composition and Properties of Drilling and Completion Fluids, 6th ed.; Gulf Professional Publishing: Houston, TX, 2011.
4. Bourgoyne, A.; Millheim, K.; Chenevert, M. Applied Drilling Engineering. 1984.
5. Mohamed, A.; Elkatatny, S. A.; Mahmoud, M. A.; Shawabkeh, R. A.; Al-Majed, A. A. In The Evaluation of Micronized Barite as a Weighting Material for Completing HPHT Wells, SPE Middle East Oil and Gas Show and Conference, Manama, Kingdom of Bahrain, 2017.
6. Mohamed, A.; Elkatatny, S. A.; Mahmoud, M. A.; Shawabkeh, R. A.; Al-Majed, A. A. Evaluating the Effect of Using Micronised Barite on the Properties of Water-Based Drilling Fluids. Int. J. Oil, Gas Coal Technol. 2020, 25, 1−18.
7. Finger, J.; Blankenship, D. Handbook of Best Practices for Geothermal Drilling; Sandia National Laboratories: Albuquerque, 2010.
8. Shadravan, A.; Amani, M. HPHT 101-What Petroleum Engineers and Geoscientists Should Know About High Pressure High Temperature Wells Environment. Energy Sci. Technol. 2012, 4, 36−60.
9. De Angelis, R.; Holdeman, M.; Piccock, G.; Levy, W.; Figueroa, H.; Lyon, R. In Challenges of Drilling in the Chilean Altiplano, SPE/IADC Drilling Conference and Exhibition, Amsterdam, The Netherlands, 2011.
10. Reinsch, T.; Regenspurg, S.; Feldbusch, E.; Saadat, A.; Huenges, E.; Erbas, K.; Zimmermann, G.; Henninges, J. Reverse Cleanout in a Geothermal Well: Analysis of a Failed Coiled Tubing Operation. SPE Prod. Oper. 2015, 30, 312−320.
11. Kiran, R.; Salehi, S. In Assessing the Relation between Petrophysical and Operational Parameters in Geothermal Wells: A Machine Learning Approach, Proceedings of 45th Workshop on Geothermal Reservoir Engineering, San Francisco, California, 2020.
12. Tehrani, M. A.; Poppelste, A.; Guarneri, A.; Carminati, S. In Water-Based Drilling Fluid for HP/HT Applications, SPE International Symposium on Oilfield Chemistry, Houston, Texas, 2007.
13. Chemwotei, S. C. Geothermal Drilling Fluids, 2011; Vol. 10.
14. Kruszewski, M.; Wirtz, Y. Reverse Cleanout in a Geothermal Well: Analysis of a Failed Coiled Tubing Operation. SPE Prod. Oper. 2015, 30, 312−320.
15. Sukhoboka, O. In Drilling Fluid Rheology under High Pressure High Temperature Conditions and Its Impact on the Rate of Penetration, SPE Bergen One Day Seminar, Bergen, Norway, 2017.
Sag in Invert Emulsion Drilling Fluids. Mixture, an Enhanced Weighting Agent for the Elimination of Barite Sag 2004.

Barite Sag Complex Salt Diapirs/Paleocene Reservoir Case Study - ECD Management Strategy Solves Lost Circulation Issues on Determining Weighting Material Sag in Drilling Fluid and Relationship to Issues.

Sag Management: Challenges, Strategies, Opportunities Drilling Fluid. Barite-Ilmenite weighting Material to Prevent Barite Sag in Water-Based Fluids. G.; Pedersen, E. S.; Turner, J.; Harris, M. J. In IADC/SPE Asia Pacific Drilling Conference and Exhibition, Dallas, Texas, 2002.

Rheological Properties on Hole Cleaning - 2014

Zamora, M.; Slater, K. S. Barite Sag: Measurement, Modelling and Morphological Properties. IADC/SPE Drilling Conference and Exhibition, San Diego, California, 2012.

(27) Murtaza, M.; Tarig, Z.; Mahmoud, M.; Kamal, M. S.; Al-Shehri, A. Anhydrite (Calcium Sulfate) Mineral as a Novel Weighting Material in Drilling Fluids. J. Energy Resour. Technol. 2021, 143, 345.

(28) Bern, P. A.; Zamora, M.; Hempflh, A. T.; Marshall, D.; Omland, T. H.; Morton, E. K. In Field Monitoring of Weight-Material Sag, 2010 AADE Fluids Conference and Exhibition, Houston, Texas, 2010.

(29) Omland, T. H.; Saasen, A.; Amund, P. Detection Techniques Determining Weighting Material Sag in Drilling Fluid and Relationship to Rheology: Annual Transactions-nordic Rheology Society, 2007.

(30) Basfar, S.; Mohamed, A.; Elkatauty, S. Barite-Micromax Mixture, an Enhanced Weighting Agent for the Elimination of Barite Sag in Invert Emulsion Drilling Fluids. J. Pet. Explor. Prod. Technol. 2020, 10, 2427.

(31) Hanson, P. M.; Trigg, T. K.; Rachal, G.; Zamora, M. In Investigation of Barite “sag” in Weighted Drilling Fluids in Highly Deviated Wells, SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 2013.

(32) Wilson, A. ECD-Management Strategy Solves Lost Circulation Issues. J. Pet. Technol. 2014, 66, 77–80.

(33) Pramusanto, P.; Nurrochman, A.; Mamby, H. E.; Nugraha, P. High Strength Lightweight Concrete with Expandable Perlite as the Aggregate. IOP Conf. Ser. Mater. Sci. Eng. 2020, 789, 1527.

(34) Pramusanto, P.; Nurochman, A.; Mamby, H. E.; Nugraha, P. High Strength Lightweight Concrete with Expandable Perlite as the Aggregate. IOP Conf. Ser. Mater. Sci. Eng. 2020, 789, 1527.

(35) Husein, N.; Hui, H. T.; Nadaraja, K. Experimental Investigation of Hole Cleaning in Directional Drilling by Using Nano-Enhanced Water-Based Drilling Fluids. J. Pet. Sci. Eng. 2019, 176, 220–231.

(36) Olei, T. N.; Lund, B.; Saasen, A.; Sangesland, S.; Linga, H.; Gyland, K. R.; Kawai, M. In Barite Sag Measurements, SPE/IADC Drilling Conference, Galveston, Texas, 2020.

(37) Chilingarian, G. V.; Alp, E.; Eshu, S.; Gonzales, S.; Ronald, J.; et al. Drilling Fluid Evaluation Using Yield Point-Plastic Viscosity Correlation. Energy Sources 1986, 8, 233–244.

(38) Power, D.; Zamora, M. In Drilling Fluid Yield Stress: Measurement Techniques for Improved Understanding of Critical Drilling Fluid Parameters, AADE National Technology Conference, Houston, Texas, 2003.

(39) Maxey, J. Rheological Analysis of Static and Dynamic Sag in Drilling Fluids; Annual Transactions-Nordic Rheology Society, 2007.

(40) Bui, B.; Saasen, A.; Maxey, J.; Obayyoglu, M.; Miska, S. Z.; Yu3, M.; Takach, N. E. Viscoelastic Properties of Oil-Based Drilling Fluids. Annu. Trans. Nord. Rheol. Soc. 2012, 20, 33–47.

(41) Kilic, A. M.; Kahraman, E.; Kilic, O. In Evaluation of the Use of Perlite in Industry Evaluation of the Use of Perlite in Industry, International Congress on Engineering and Architecture (ENAR-2018), 2018.

(42) Bageri, B. S.; Adbayo, A. R.; Al Jaberi, J.; Patil, S. Effect of Perlitic Particles on the Filtration Properties of High-Density Barite Weighted Water-Based Drilling Fluid. Powder Technol. 2020, 360, 1157–1166.

(43) Hamza, A.; Koscierzka, I. The Effect of Expanded Perlite on Fired Clay Bricks. J. Phys. Conf. Ser. 2020, 1527, No. 012032.

(44) Pramusanto, P.; Nurochman, A.; Mamby, H. E.; Nugraha, P. High Strength Lightweight Concrete with Expandable Perlite as the Aggregate. IOP Conf. Ser. Mater. Sci. Eng. 2020, 789, No. 042040.

(45) Varun Teja, K.; Meena, T. Experimental Exploration of Perlite Concrete under Elevated Temperatures. Indian Constr. J. 2019, 93, 27–33.

(46) Muthupriya, P.; Shobana, K. S. Utilization of Industrial Waste Perlite Powder and Vermiculite in Self Compacting Concrete. Int. J. Eng. Res. Technol. 2020, V9, 782–789.

(47) El Mir, A.; Nehme, S. G. Utilization of Industrial Waste Perlite Powder in Self-Compacting Concrete. J. Cleaner Prod. 2017, 156, 507–517.

(48) Wang, X.; Chen, T.; Zheng, G. Perlite as the Partial Substitute for Organic Bulking Agent during Sewage Sludge Composting. Environ. Geochem. Health. 2020, 42, 1517–1529.
Ramos, F.; Sanz, Y.; Villa, R. E.; Woutersen, R.; Brozzi, R.; Galobart, J.; Gregoretti, L.; López-Gálvez, G.; Innocenti, M. L.; Vettori, M. V.; Sofianidis, K. Statement on the Safety and Efficacy of Perlite for Ruminants and Poultry. EFSA J. 2020, 18, No. e06138.

(60) Samar, M.; Saxena, S. Study of Chemical and Physical Properties of Perlite and Its Application in India. Int. J. Sci. Technol. Manage. 2016, 5, 70–80.

(61) Skalle, P.; Backe, K. R.; Lyomov, S. K.; Sveen, J. Barite Segregation in Inclined Boreholes. J. Can. Pet. Technol. 1999, 38, 1–6.

(62) Power, D.; Zamora, M. In Drilling Fluid Yield Stress: Measurement Techniques for Improved Understanding of Critical Drilling Fluid Parameters, AADE-03 National Technology Conference “Practical Solutions for Drilling Challenges”, Houston, Texas, 2003.

(63) Majidi, R.; Miska, S. Z.; Yu, M.; Thompson, L. G.; Zhang, J. Quantitative Analysis of Mud Losses in Naturally Fractured Reservoirs: The Effect of Rheology. SPE Drill. Completion 2010, 25, 509–517.

(64) Liang, T.; Gu, F.; Yao, E.; Zhang, L.; Yang, E.; Liu, G.; Zhou, F. Formation Damage Due to Drilling and Fracturing Fluids and Its Solution for Tight Naturally Fractured Sandstone Reservoirs. Geofluids 2017, 2017. DOI: 10.1155/2017/9350967.

(65) Khatib, Z. I. In Prediction of Formation Damage Due to Suspended Solids: Modeling Approach of Filter Cake Buildup in Injectors, SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 1994.

(66) Siddig, O.; Mahmoud, A. A.; Elkatatny, S. A Review of Different Approaches for Water-Based Drilling Fluid Filter Cake Removal. J. Pet. Sci. Eng. 2020, 192, No. 107346.

(67) Amanullah, M.; Al-Arfaj, M. K. In Method and Apparatus to Reduce the Probability of Differential Sticking, IADC/SPE Asia Pacific Drilling Technology Conference, Singapore, 2016.

(68) Huang, S.; Guo, X.; Duan, W.; Cheng, X.; Zhang, X.; Li, Z. Degradation of High Molecular Weight Polyacrylamide by Alkali-Activated Persulfate: Reactivity and Potential Application in Filter Cake Removal before Cementing. J. Pet. Sci. Eng. 2019, 174, 70–79.

(69) Javeri, S. M.; Haindade, Z. W.; Jere, C. B. In Mitigating Loss Circulation and Differential Sticking Problems Using Silicon Nanoparticles, SPE/IADC Middle East Drilling Technology Conference and Exhibition, Muscat, Oman, 2011.