SUSTAINABLE ENGINEERING

(eISSN:3083-8231)
Article
Volume 3, 2026
https://doi.org/10.51200/susten.v3i1.7594

Sensitivity Analysis of Torque and Drag in Offshore Extended Reach Drilling Wells Using a Simulation-Based Approach

Hagilash Paramasivam[1], Kamilia Sharir[1]*, Mohd Syazwan Mohd Musa[1], Siti Mardhiah Mohd Anuar[1]

[1] Oil and Gas Engineering Program, Faculty of Engineering, Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia
*Correspondence: kamilia.sharir@ums.edu.my

Received: 23 April 2026, Accepted: 30 June 2026

Abstract: Extended reach drilling (ERD) is widely applied in offshore hydrocarbon development to access distant reservoirs while minimizing surface infrastructure. However, long inclined and horizontal sections in ERD wells increase torque and drag forces, which may lead to stuck pipe, excessive mechanical loading, and reduced drilling efficiency. This study presents a simulation-based sensitivity analysis to evaluate the combined influence of build-up rate (BUR) and bottom hole assembly (BHA) stabilizer configuration on torque and drag behaviour in an offshore ERD well. The novelty of this study lies in the integrated assessment of trajectory curvature and stabilizer configuration under multiple drilling operational conditions rather than evaluating these parameters independently. Well trajectories were generated using COMPASS, and mechanical load analysis was performed using WELLPLAN under run-in-hole, pull-out-of-hole, rotating-on-bottom, and rotating-off-bottom conditions. Three BUR values, namely 2.0°, 2.5°, and 3.0°/100 ft, and three stabilizer configurations consisting of two, four, and six stabilizers were evaluated, resulting in nine simulation scenarios. The results show that reducing BUR from 3.0°/100 ft to 2.0°/100 ft decreased pick-up drag from 82.3 kip to 77.7 kip and slack-off drag from 75.7 kip to 72.9 kip. Although additional stabilizers may increase localized contact points, the six-stabilizer configuration improved drillstring centralization and trajectory stability, resulting in the most favourable torque and drag response when combined with the lowest BUR. The optimal configuration was identified as BUR 2.0°/100 ft with six stabilizers. These findings demonstrate that integrated optimization of trajectory design and BHA configuration can reduce mechanical loading and support safer, more efficient offshore ERD operations.

Keywords: Extended reach drilling; torque and drag; build-up rate; bottom hole assembly; drilling optimization

1. Introduction

The increasing demand for hydrocarbons has driven the oil and gas industry toward more complex drilling environments, particularly offshore developments where reservoirs are located far from surface facilities. Conventional vertical wells are often insufficient for accessing such reservoirs, leading to the widespread adoption of directional and horizontal drilling techniques [1–3].

Extended reach drilling (ERD) represents an advanced form of directional drilling, characterized by large horizontal displacements relative to true vertical depth (TVD). ERD wells are commonly defined by a horizontal displacement-to-TVD ratio exceeding two, enabling operators to maximize reservoir contact while minimizing the number of drilling platforms required [1,11]. This approach offers significant economic and environmental advantages, including reduced infrastructure footprint and lower development costs.

Despite these benefits, ERD operations introduce substantial mechanical challenges. As wellbore length and inclination increase, frictional interactions between the drillstring and the wellbore become more pronounced. These interactions generate torque and drag forces that can lead to operational issues such as drillstring buckling, inefficient hole cleaning, and increased non-productive time (NPT) [5,14,16]. These challenges are particularly critical in offshore environments where operational constraints are more stringent.

Previous studies have investigated torque and drag behaviour using analytical and numerical models, focusing on factors such as well trajectory, drillstring mechanics, and drilling fluid properties [13,16]. However, most studies consider these parameters independently. Limited research has addressed the combined influence of build-up rate (BUR) and stabilizer configuration, particularly in offshore ERD wells where both curvature and mechanical support significantly influence drilling performance.

Therefore, this study aims to evaluate the sensitivity of torque and drag to variations in BUR and BHA stabilizer configuration using a simulation-based approach. The findings are expected to provide practical insights for optimizing drilling design and improving operational efficiency in ERD wells.

2. Materials and Methods

2.1 Simulation Workflow

This study used a simulation-based workflow to evaluate the effects of build-up rate (BUR) and Bottom Hole Assembly (BHA) stabilizer configuration on torque and drag behaviour in an offshore Extended Reach Drilling (ERD) well. The procedure involved four main stages: trajectory design, BHA configuration, torque and drag simulation, and sensitivity analysis. The overall workflow is shown in Figure 1.

2.2 Well Trajectory Design

Three ERD well trajectories were generated using Halliburton Landmark COMPASS, while Halliburton Landmark WELLPLAN was used for torque and drag simulation. The build-up rates evaluated were 2.0°, 2.5°, and 3.0°/100 ft. The kick-off point and target depth were kept constant for all cases to ensure that the effect of trajectory curvature could be compared systematically. The representative ERD well has a horizontal displacement of approximately 4636 m and a true vertical depth of 1653 m, giving a horizontal displacement-to-TVD ratio of approximately 2.8. The analysis focused on the 8½-inch hole section.

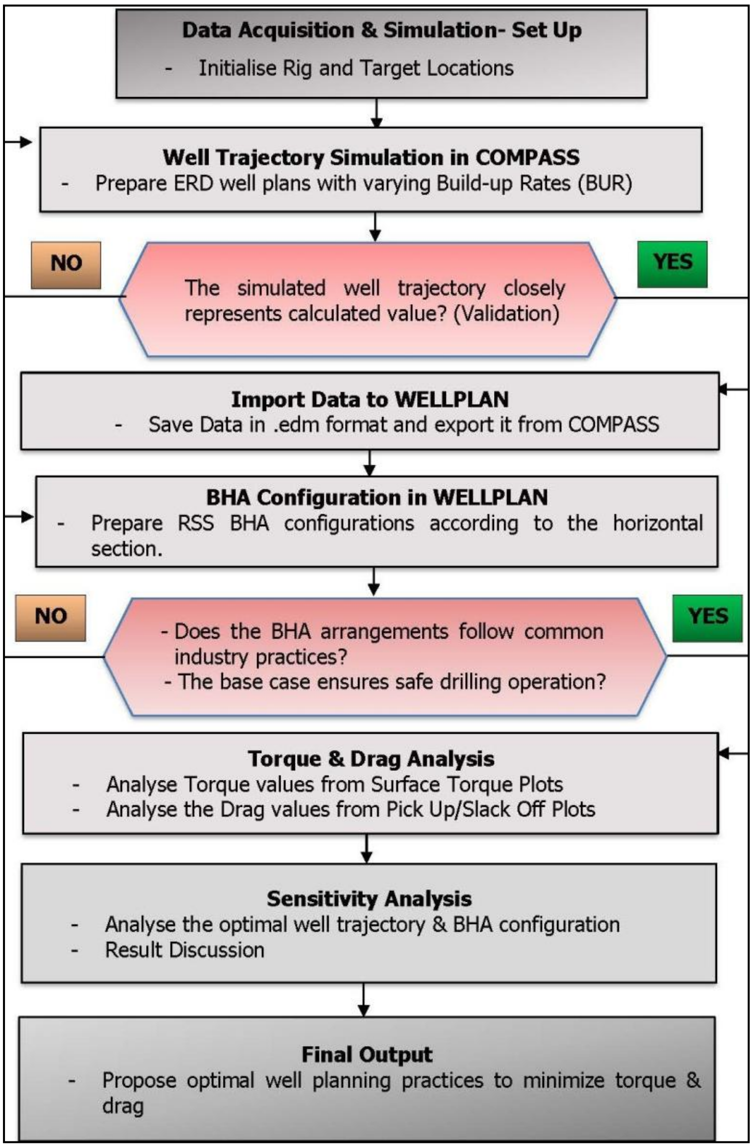


Figure 1. Simulation workflow for torque and drag analysis of the ERD well.

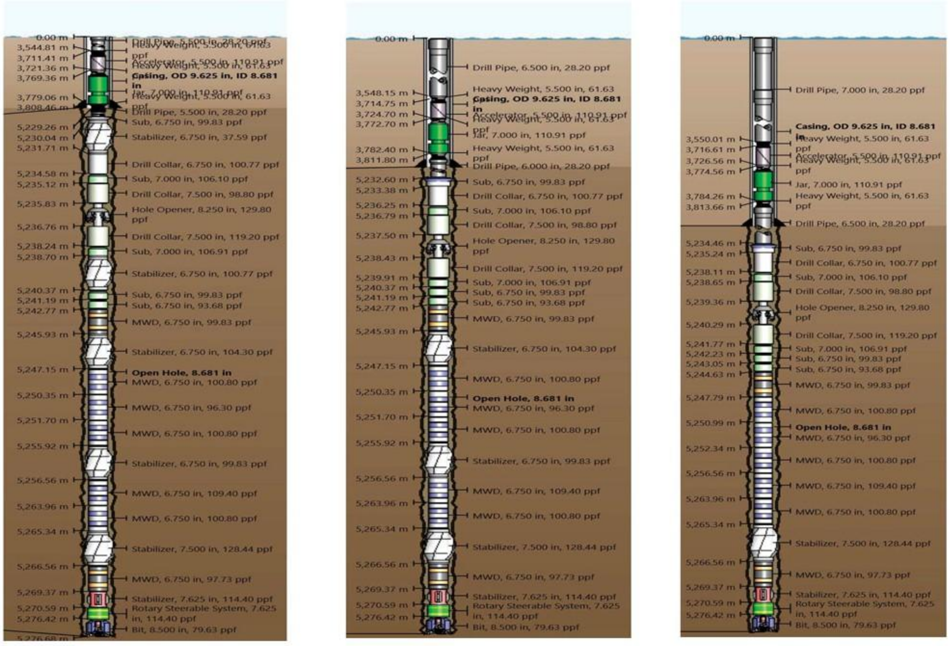
2.3 BHA Stabilizer Configuration

Three BHA stabilizer configurations were evaluated (Figure 2). The first configuration consisted of a near-bit stabilizer and five additional spaced stabilizers, resulting in six stabilizers. The second configuration consisted of a near-bit stabilizer and three additional stabilizers, resulting in four stabilizers. The third configuration consisted of a near-bit stabilizer and one additional stabilizer, resulting in two stabilizers. Each stabilizer configuration was simulated for the three BUR cases, producing nine simulation scenarios.

2.4 Torque and Drag Simulation Parameters

Torque and drag simulations were performed using Halliburton Landmark WELLPLAN software within the Engineer's Desktop well construction platform. Oil-based mud (OBM) with a mud weight of 10 ppg was used as the drilling fluid. Although the target depth of the studied ERD well is approximately 1700 m, OBM was selected to represent offshore ERD drilling conditions where improved lubricity, reduced frictional resistance, shale inhibition, and borehole stability are important. The total flow area (TFA) at the drill bit was set to

0.8437 in². Friction factors of 0.2 and 0.3 were assigned for casing and open-hole sections, respectively. Rotary Steerable Systems (RSS) were incorporated to represent modern ERD drilling practices that allow continuous drillstring rotation while maintaining directional control.



(a) six-stabilizer configuration (b) four-stabilizer configuration (c) two-stabilizer configuration

Figure 2. Bottom Hole Assembly configurations used in the simulation, generated based on the BHA arrangements simulated in WELLPLAN.

2.5 Operational Conditions and Sensitivity Analysis

Torque and drag responses were analysed under four operational conditions: run-in-hole (RIH), pull-out-of-hole (POOH), rotating-on-bottom (ROB), and rotating-off-bottom (ROFFB). The output torque and drag values were compared across the nine simulation scenarios to identify the influence of BUR and stabilizer configuration on mechanical loading. The optimal configuration was determined based on the lowest torque and drag response while maintaining suitable BHA stability and trajectory control.

3. Results and Discussion

The ERD well trajectory generated using COMPASS software is presented in Figure 3. The well profile follows a build–hold–build–hold trajectory design commonly used in extended reach wells. The trajectory gradually deviates from the vertical section toward the horizontal interval to reach the target reservoir while maintaining the required horizontal displacement. Such trajectory designs are widely applied in offshore ERD developments to maximize reservoir exposure and improve hydrocarbon recovery while minimizing the need for additional drilling platforms [1,11].

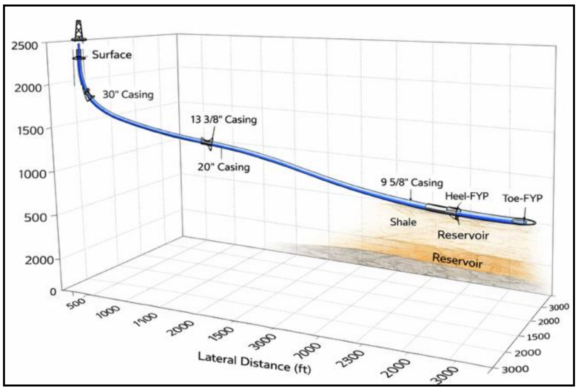


Figure 3. Simulated ERD well trajectory generated using COMPASS software.

To evaluate the influence of trajectory curvature on mechanical loads, three well trajectories were designed using BUR values of 2.0°/100 ft, 2.5°/100 ft, and 3.0°/100 ft, while maintaining the same kick-off point and target depth. The simulated torque distributions along the well path for these trajectories are shown in Figure 4. The results indicate that higher BUR values produce higher torque levels along the drillstring.

This behaviour can be explained by the increase in wellbore curvature associated with higher BUR values. Steeper build sections generate larger bending forces within the drillstring and increase the normal contact forces between the drillstring and the wellbore wall. Since frictional force is directly proportional to the normal contact force, higher curvature results in greater frictional resistance during drilling operations. Similar trends have been reported in previous torque and drag modelling studies for highly deviated and horizontal wells [5], [14], [16]. The results, therefore, confirm that well trajectory curvature is a dominant factor controlling torque distribution in ERD wells.

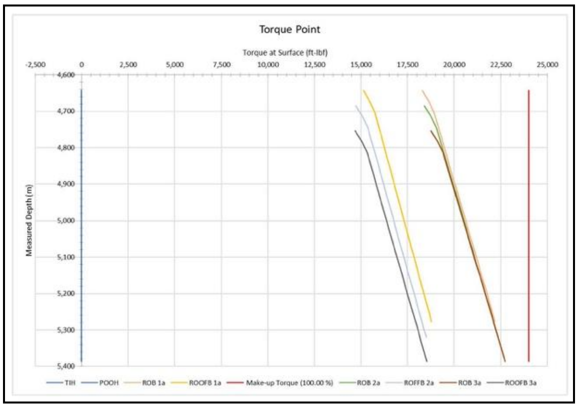


Figure 4. Comparison of torque distribution along the wellbore for different build-up rate (BUR) scenarios.

The increasing trend observed in the torque profiles is primarily associated with increasing wellbore curvature along the build sections of the trajectory. As inclination increases, the drillstring experiences greater normal contact forces against the wellbore wall. These contact forces increase frictional resistance along the drillstring, which subsequently leads to higher torque and drag values. Conversely, trajectories with lower BUR produce smoother curvature profiles, reducing drillstring contact forces and resulting in lower mechanical loads along the well path.

The effect of BUR on axial drag is illustrated in Figure 5. Similar to the torque results, axial drag increases as the BUR increases. Wells with higher curvature experience greater mechanical interaction between the drillstring and the wellbore wall, which increases frictional resistance during tripping operations.

This effect becomes more pronounced in ERD wells due to the long horizontal sections that significantly increase the contact length between the drillstring and the wellbore. As the contact length increases, frictional forces accumulate along the well path, resulting in higher drag forces during both pick-up and slack-off operations. Previous studies have also highlighted that drag forces become a critical operational constraint in ERD wells with extended horizontal intervals [5], [14].

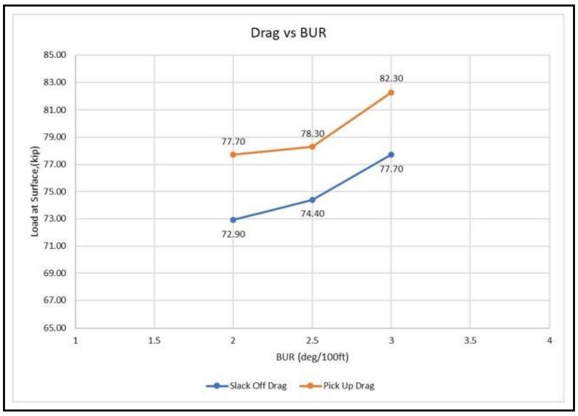


Figure 5. Variation of axial drag along the wellbore for different build-up rate (BUR) cases.

The numerical results for the pick-up and slack-off drag values are summarized in Table 1. The highest pick-up drag value of 82.3 kip occurs in Case 1a with a BUR of 3.0°/100 ft, while the lowest value of 77.7 kip is observed in Case 3a with a BUR of 2.0°/100 ft. Similarly, slack-off drag decreases from 75.7 kip to 72.9 kip as the BUR decreases.

These results demonstrate that smoother, well trajectories with lower curvature can significantly reduce mechanical resistance along the drillstring. Reduced curvature minimizes the magnitude of normal contact forces between the drillstring and the wellbore wall, which subsequently decreases frictional resistance. This observation is consistent with previously reported torque and drag modelling results for deviated wells and ERD operations [5], [16].

Table 1. Pick-up and slack-off drag results for different BUR cases.

Case	BUR (°/100 ft)	Pick-Up Drag (kip)	Slack-Off Drag (kip)
Case 1a	3.0	82.3	75.7
Case 2a	2.5	78.3	74.4
Case 3a	2.0	77.7	72.9

Note: kip refers to kilopound-force, where 1 kip = 1,000 pounds-force (lbf).

Pick-up drag represents the axial force required to pull the drillstring upward during tripping operations, whereas slack-off drag refers to the force experienced when lowering the drillstring into the wellbore. The difference between these two forces occurs due to frictional interaction between the drillstring and the wellbore wall. In highly deviated wells, the drillstring tends to rest against the low side of the wellbore, increasing frictional resistance and resulting in higher pick-up drag compared to slack-off drag.

In addition to well trajectory design, the configuration of stabilizers within the Bottom Hole Assembly plays an important role in determining torque and drag behaviour. In this study, three stabilizer configurations were evaluated, consisting of assemblies with six stabilizers, four stabilizers, and two stabilizers. These configurations represent BHA assemblies with varying stiffness characteristics and different numbers of contact points along the wellbore. Stabilizers are commonly used to improve drillstring centralization and increase resistance to buckling in directional drilling operations [2].

The torque response for the different stabilizer configurations is shown in Figure 6. The results indicate that stabilizer placement influences the torque distribution along the drillstring. Increasing the number of stabilizers generally increases the stiffness of the BHA and the number of potential contact points between the drillstring and the wellbore wall. While this may increase localized frictional forces, stabilizers also improve drillstring centralization and trajectory stability, which helps maintain the planned well path during drilling operations. Similar observations have been reported in studies involving rotary steerable systems and directional drilling assemblies used in complex well trajectories [3], [4], [20].

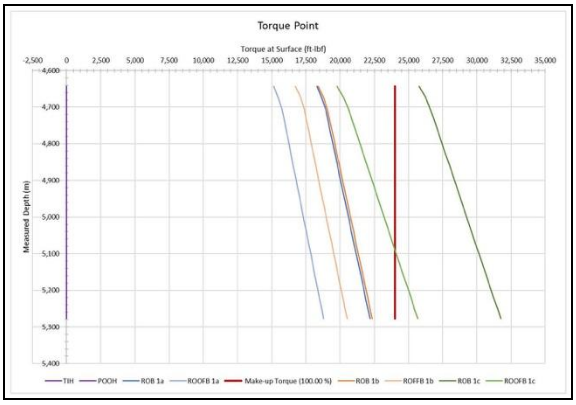


Figure 6. Comparison of torque distribution along the drillstring for different Bottom Hole Assembly stabilizer configurations.

The relationship between axial drags and stabilizer configuration is presented in Figure 7. The results show that BHA assemblies with fewer stabilizers tend to exhibit lower drag values due to reduced contact points with the wellbore wall. However, insufficient stabilizer support may reduce trajectory stability and drilling control, particularly in highly deviated well sections. Therefore, an optimal balance between stabilizer support and frictional resistance is required when designing BHA configurations for ERD wells [2], [3].

Based on the overall simulation results, the configuration that produced the lowest torque and drag values was the trajectory with a BUR of 2.0°/100 ft combined with a six-stabilizer BHA configuration. Although additional stabilizers may increase localized contact forces, this configuration provides improved drillstring stability and better trajectory control, which helps reduce excessive wellbore contact along critical sections of the well path.

The observed trends in torque and drag behaviour are consistent with previously reported findings in extended reach drilling studies, which indicate that increased wellbore curvature and additional drillstring contact points can increase frictional forces and mechanical loading during drilling operations [1], [5], [14], [16]. These findings highlight the importance of optimizing both well trajectory design and BHA configuration during the planning stage of ERD wells.

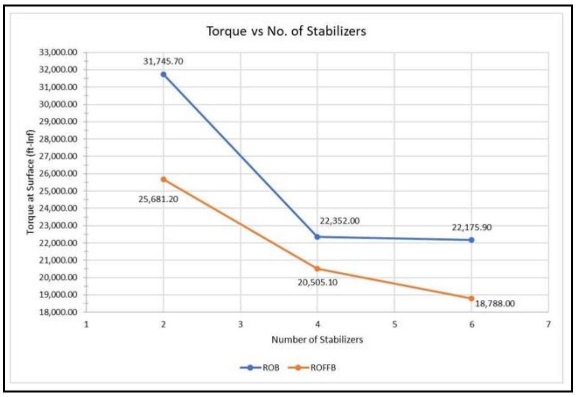


Figure 7. Variation of axial drag along the wellbore for different stabilizer configurations in the Bottom Hole Assembly.

Overall, the results demonstrate that careful optimization of BUR and stabilizer configuration can significantly influence torque and drag behaviour in ERD wells. Proper trajectory design combined with appropriate stabilizer placement can reduce mechanical loading on the drillstring, improve drilling efficiency, and minimize operational risks such as excessive torque, high drag forces, and potential stuck-pipe incidents. Such optimization strategies are therefore essential for achieving safe and efficient drilling performance in modern offshore ERD developments [1], [11].

The trends observed in this study are consistent with previous torque and drag modelling investigations in highly deviated and horizontal wells. Increased wellbore curvature has been shown to increase frictional forces acting on the drillstring, resulting in higher torque and drag values [5,16]. Similar observations have also been reported in previous torque and drag modelling studies, where trajectory design and wellbore curvature were identified as critical factors controlling mechanical loads in extended reach drilling operations [16]. The present results, therefore, reinforce the importance of optimizing well trajectory design and BHA configuration during the planning stage of ERD wells.

This study focuses on simulation-based evaluation of torque and drag behaviour using representative drilling parameters. Field validation using real drilling data could further improve the accuracy of torque and drag predictions. Future studies may also incorporate additional factors such as drilling fluid rheology, wellbore tortuosity, and cuttings transport efficiency to provide a more comprehensive analysis of ERD drilling performance.

4. Conclusions

This study evaluated the sensitivity of torque and drag behaviour to build-up rate (BUR) and Bottom Hole Assembly (BHA) stabilizer configuration in an offshore Extended Reach Drilling (ERD) well using a simulation-based approach. The objective was to identify how trajectory curvature and stabilizer arrangement influence mechanical loading under common drilling operational conditions.

The results show that BUR is a key factor controlling torque and drag response. A higher BUR increases wellbore curvature, which increases drillstring–wellbore contact forces and frictional resistance. Reducing the BUR from 3.0°/100 ft to 2.0°/100 ft decreased pick-up drag from 82.3 kip to 77.7 kip and slack-off drag from 75.7 kip to 72.9 kip. The stabilizer configuration also influenced the mechanical response of the BHA. Although fewer stabilizers may reduce contact points, the six-stabilizer configuration provided better drillstring centralization and trajectory stability. The most favourable configuration was identified as BUR 2.0°/100 ft combined with a six-stabilizer BHA.

The findings highlight the importance of optimizing both well trajectory and BHA design during the planning stage of offshore ERD wells. From a practical perspective, reducing excessive curvature and selecting an appropriate stabilizer arrangement can help minimize mechanical loading, improve drilling efficiency, and reduce the risk of operational problems such as excessive torque, high drag, and stuck pipe.

This study is limited to simulation-based analysis using representative drilling parameters. Field validation using actual drilling data is recommended to improve the reliability of the predicted torque and drag responses. Future studies should also consider additional parameters such as drilling fluid rheology, wellbore tortuosity, hole cleaning efficiency, cuttings transport, and real-time drilling data integration.

Overall, this study demonstrates that integrated optimization of BUR and BHA stabilizer configuration provides a practical approach for improving mechanical performance and operational reliability in offshore ERD wells.

Funding

This research received no external funding.

Acknowledgments

The authors acknowledge Universiti Malaysia Sabah for providing institutional and technical support for this study.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Agbaji, A. L. 2010. "Optimizing the Planning, Design and Drilling of Extended Reach and Complex Wells." Abu Dhabi International Petroleum Exhibition and Conference. https://doi.org/10.2118/136901-MS

[2] Akgun, F. 1999. "Optimum Spacing of Multiple Stabilizers to Increase Critical Buckling Load of BHA in Slim Hole Drilling." SPE Asia Pacific Oil and Gas Conference and Exhibition. https://doi.org/10.2118/54322-MS

[3] Al Dabyah, A., Biscaro, E., and Mayer, H. 2016. "New Generation of Rotary Steerable System Enables Higher BUR and Performance." SPE Annual Technical Conference and Exhibition. https://doi.org/10.2118/181358-MS

[4] Alrushud, A., Mohammad, M., Oliveira, V., and Zahrani, B. 2018. "Effect of the Rotary Steerable System Steering Mechanism on Wellbore Tortuosity in Horizontal Wells." SPE/IADC Middle East Drilling Technology Conference and Exhibition. https://doi.org/10.2118/189408-MS

[5] Razzaq, A. A. A., and Neamah, H. A. 2019. "Torque and Drag Forces Challenges in Highly Deviated Oil Well (Zubair Oil Field)." Journal of Petroleum Research and Studies 9(1): 21–34. https://doi.org/10.52716/jprs.v9i1.271

[6] Ashena, R., Elmgerbi, A., Rasouli, V., Ghalambor, A., Rabiei, M., and Bahrami, A. 2020. "Severe Wellbore Instability in a Complex Lithology Formation Necessitating Casing While Drilling and Continuous Circulation System." Journal of Petroleum Exploration and Production Technology 10(4): 1511–1532. https://doi.org/10.1007/s13202-020-00834-3

[7] Azar, J. J. 2006. "Drilling Problems and Solutions." In Drilling Engineering, 433–454. Society of Petroleum Engineers. https://doi.org/10.2118/9781555631147-ch10

[8] Barrera, E., Perez, C., Gomez, J. M., Alarcon, J., Torres, M. A., Zapata, A., and Laguado, P. 2024. "Risk Mitigation and Drilling Time Reduction Practices with Optimized Wellbore Geometries Implemented in Offshore Shallow-Water Tertiary Wells in Gulf of Mexico." IPTC Conference. https://doi.org/10.2523/IPTC-23495-MS

[9] Berger, P. E., and Sele, R. 1998. "Improving Wellbore Position Accuracy of Horizontal Wells by Using a Continuous Inclination Measurement From a Near Bit Inclination MWD Sensor." SPE International Conference on Horizontal Well Technology. https://doi.org/10.2118/50378-MS

[10] Bizhani, M., Rodriguez Corredor, F. E., and Kuru, E. 2016. "Quantitative Evaluation of Critical Conditions Required for Effective Hole Cleaning in Coiled-Tubing Drilling of Horizontal Wells." SPE Drilling & Completion 31(3): 188–199. https://doi.org/10.2118/174404-PA

[11] Chima, J., Umarin, I., Kunhiveetil, D., Otaif, H., Al Dabyah, A., and Zubairi, B. 2016. "Proper Planning Supported by Latest Technology Leads to Drilling the Longest 8.5-in. Section in an Extended-Reach Well: Case Study." Offshore Technology Conference. https://doi.org/10.4043/26821-MS

[12] Costa, S. S., Stuckenbruck, S., da Fontoura, S. A. B., and Martins, A. L. 2008. "Simulation of Transient Cuttings Transportation and ECD in Wellbore Drilling." Europec/EAGE Conference and Exhibition. https://doi.org/10.2118/113893-MS

[13] Cunha, A., Soize, C., and Sampaio, R. 2015. "Computational Modeling of the Nonlinear Stochastic Dynamics of Horizontal Drillstrings." Computational Mechanics 56(5): 849–878. https://doi.org/10.1007/s00466-015-1206-6

[14] Dawson, R. 1984. "Drill Pipe Buckling in Inclined Holes." Journal of Petroleum Technology 36(10): 1734–1738. https://doi.org/10.2118/11167-PA

[15] Kaiser, M. J. 2022. "Offshore Oil and Gas Records Circa 2020." Ships and Offshore Structures 17(1): 205–241. https://doi.org/10.1080/17445302.2020.1827633

[16] Nour, M., Elgibaly, A. A., Farahat, M. S., and Mahmoud, O. 2022. “Novel Torque and Drag Model for Drilling Two-Dimensional High-Angle Wells.” ACS Omega 7(14): 12374–12389. https://doi.org/10.1021/acsomega.2c00924

[17] Oseh, J. O., Mohd Norddin, M. N. A., Ismail, I., Gbadamosi, A. O., Agi, A., and Ismail, A. R. 2020. “Experimental Investigation of Cuttings Transportation in Deviated and Horizontal Wellbores Using Polypropylene–Nanosilica Composite Drilling Mud.” Journal of Petroleum Science and Engineering 189: 106958. https://doi.org/10.1016/j.petrol.2020.106958

[18] Ovsepian, E. E., Leusheva, E. L., and Morenov, V. A. 2021. “Drilling Mud Upward Velocity Modelling in Ansys CFX Software.” IOP Conference Series: Earth and Environmental Science 931(1): 012020. https://doi.org/10.1088/1755-1315/931/1/012020

[19] Pandya, S., Ahmed, R., and Shah, S. 2019. “Experimental Study on Wellbore Cleanout in Horizontal Wells.” Journal of Petroleum Science and Engineering 177: 466–478. https://doi.org/10.1016/j.petrol.2019.02.069

[20] Park, J., Kim, J., Park, B., and Myung, H. 2013. “Design and Analysis of a New Hybrid Rotary Steerable System for Directional Drilling.” IEEE ISR 2013: 1–3. https://doi.org/10.1109/ISR.2013.6695613