Advances and Challenges of Directional Drilling in the Pre-Salt and Other Offshore Reserves

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Abstract- ***Directional drilling has become an essential technology for offshore reserve exploration, especially in the pre-salt, due to the technical challenges posed by great depths, high pressure, and geological instability. This technique optimizes oil extraction by reducing operational costs and environmental impacts while minimizing the need for multiple vertical wells. Among the main difficulties faced in pre-salt drilling are the fluidity of salt layers, which can lead to well collapse, and the complexity of carbonate formations, which hinder penetration rates. To overcome these challenges, the industry has invested in technologies such as rotary steerable systems (RSS), real-time monitoring sensors, and artificial intelligence, allowing immediate adjustments during operations and greater precision in drill bit trajectory. Case studies demonstrate how these solutions have been applied in different offshore regions. In Brazil, for instance, projects in the Atlanta field and other pre-salt areas highlight the use of horizontal drilling to maximize reservoir drainage and reduce the need for additional infrastructure. Research in other countries, such as Kazakhstan and Iraq, shows that advanced techniques, including the use of polymer-based drilling fluids and detailed geological modeling, have been effective in mitigating issues such as mud loss and borehole collapse. The continuous evolution of directional drilling technologies not only enhances the economic viability of offshore projects but also reinforces the industry's commitment to operational efficiency and sustainability. With the growing global demand for energy, this approach is expected to continue playing a strategic role in the development of the oil and gas sector.***

Indexed Terms- ***Directional Drilling, Pre-Salt, Offshore, Real-Time Monitoring, Sustainability.***

I. INTRODUCTION

The exploration of oil in offshore pre-salt reserves represents one of the most significant advancements in the oil industry in recent decades. Located at great depths beneath thick salt layers and the ocean floor, these reservoirs pose considerable technical challenges, requiring innovative solutions to ensure safe and efficient extraction. Among the main obstacles are the extreme pressure and temperature conditions, as well as the instability of geological formations, which can compromise well integrity. In this scenario, directional drilling stands out as an essential technology, enabling production optimization and reducing operational costs.

The complexity of drilling in the pre-salt is largely due to the extreme depth and the fluidity of salt layers, which can cause well collapse and complicate drill bit trajectory control. Additionally, offshore operations require highly specialized infrastructure, including advanced platforms, support vessels, and robust monitoring systems, all of which significantly increase operational costs. To address these challenges, the industry has invested in advanced technologies, such as real-time monitoring sensors and artificial intelligence, allowing for immediate adjustments during drilling to ensure greater precision and safety.

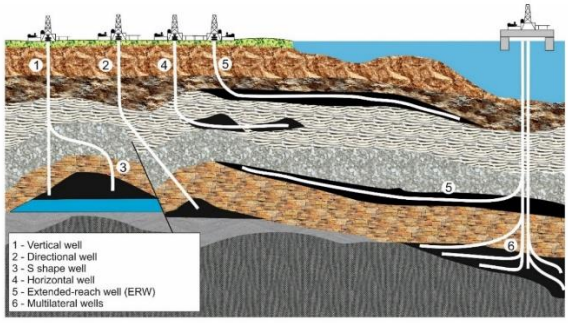

Figure 1: Different well types.
Source: El Sabeh et al. (2023).

In this context, directional drilling emerges as a strategic solution for reaching reservoirs in complex positions without the need for multiple vertical wells. The use of Rotary Steerable Systems (RSS) allows for more precise drill bit trajectory control, while Measurement While Drilling (MWD) tools provide real-time geological data, enabling immediate adjustments to maximize extraction efficiency.

Beyond improving operational performance, this technology also reduces environmental impacts by minimizing the need for new platforms and optimizing resource use. As a result, directional drilling not only makes pre-salt projects economically viable but also reinforces the industry's commitment to more sustainable practices.

The exploration of these reserves continues to present both challenges and opportunities for the oil and gas sector. Ongoing advancements in drilling and monitoring technologies promise to further enhance operational efficiency and safety, solidifying Brazil's position as a key player in the global energy market.

The study by Yuda et al. (2024) presents an integrated approach to overcoming technical challenges in landing the horizontal section in carbonate formations in the offshore region of Northwest Java. The main challenge was the spatial limitation in achieving the landing with a precise inclination of 85 degrees ±3' TVD due to the target's proximity to the platform. Additionally, the local geology posed additional risks, such as irregular trajectories, uncertainty in the depth of the Baturaja formation, and constraints on the installation of the Electrical Submersible Pump (ESP). To mitigate these challenges, the researchers implemented detailed planning, including strategic well trajectory selection, appropriate choice of Bottom Hole Assembly (BHA) components, and scenario-based simulations. Continuous monitoring and the application of geo-testing during drilling were crucial for accurately positioning the well within the reservoir, which presented a high risk of total circulation loss. As a result, well ZUG-X was successfully constructed without safety incidents or Non-Productive Time (NPT), becoming the first horizontal well drilled in the region in a negative section.

Meanwhile, the study by Macedo et al. (2023) describes a successful case of directional drilling in the Atlanta field, located off the Brazilian coast and known for its operational challenges. The presence of a shallow sandstone reservoir required the use of horizontal wells to maximize the drainage of the productive zone. The project was structured with a specific well design, initiated below the conductor casing shoe, utilizing different BHA configurations and advanced reaming techniques to expand the wellbore diameter from 12 ¼" to 20". The operation also included continuous 24/7 support for real-time optimization, including vibration control, monitoring of key performance indicators (KPIs), and automated torque and drag analysis. This approach allowed for early identification of issues such as inadequate hole cleaning, reducing the need for rework and improving drilling efficiency. The collected data provided valuable insights for future operations in unconsolidated formations, demonstrating the positive impact of automation in mitigating operational risks.

Similarly, the study by Jin et al. (2023) investigates the challenges faced in drilling pre-salt reservoirs in different parts of the world, including the Kenkyak fields in Kazakhstan and Halfaya in Iraq. In Kenkyak, the thick salt layer posed difficulties such as mud loss, pipe sticking, borehole collapse, and low rate of penetration (ROP). In the Halfaya field, well HF-10, the first exploratory vertical well in the region, faces a complex multiple-pressure regime, with high- and low-pressure layers, including salt-gypsum formations with high pore pressure. To mitigate these challenges, the research analyzed data from previous wells and conducted tests in a pilot well in Kenkyak, applying new technologies and collecting rock samples to study salt layer deformation. The introduction of a polymeric mud system and solid control devices significantly improved borehole stability and penetration rates. While 29 of the 42 wells previously drilled in the region had to be abandoned due to operational complexities, the pilot well doubled the penetration rate in the salt layer without complications. Well HF-10, scheduled for 2026, will be the deepest in Halfaya, and the implementation of the studied solutions promises to reduce risks and costs in pre-salt formation drilling.

Finally, the study by Aguiar et al. (2019) focuses on the specific challenges of drilling in the Brazilian pre-salt, a strategic area for the global oil industry. The pre-salt's microbial carbonate formations contain hard siliceous nodules, low porosity, and high resistance, making drilling difficult and reducing penetration rates, which directly impacts operational costs. The variability of these formations, often on a centimeter scale, increases the occurrence of shocks and vibrations, requiring specialized solutions. To address these difficulties, the study proposes a methodology based on advanced modeling, leading to the development of optimized drill bits with greater wear resistance and dynamic stability, enabling more efficient drilling. Additionally, a new workflow called "stratigraphic zoning for drilling" was implemented, improving decision-making processes and optimizing drilling through different geological layers. Field analysis confirms the effectiveness of this approach, pointing to promising paths for the future of pre-salt operations.

The advancements in directional drilling and associated technologies have been fundamental in overcoming the challenges of the pre-salt and other offshore reserves worldwide. With the continuous evolution of these techniques, the oil industry is strengthening its pursuit of greater efficiency, safety, and sustainability in operations.

Directional drilling has become an essential technology for offshore reserve exploration, especially in the pre-salt region, where operational challenges demand highly innovative solutions. Continuous advancements in monitoring, modeling, and automation techniques have enabled the overcoming of obstacles such as high pressure, geological instability, and formation complexity. Case studies demonstrate that the application of new strategies, such as rotary steerable systems (RSS), real-time monitoring sensors, and AI-based optimization, has been crucial in improving efficiency, reducing operational costs, and mitigating environmental risks. Beyond economic benefits, the evolution of drilling technologies contributes to the industry's sustainability by minimizing the need for new infrastructure and optimizing resource extraction. With the growing global demand for energy and the need for safer and more efficient exploration, directional drilling will continue to play a strategic role in the oil industry, ensuring that operations in challenging environments, such as Brazil's pre-salt region, become increasingly viable and sustainable.

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