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FEASIBILITY STUDY TO CONVERT A HIGHLY DEVIATED J-SHAPE WELL TO EXTENDED REACH WELL, A WELL DESING OPTIMIZATION AND ECD MANAGEMENT CASE

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ABSTRACT

Extended Reach Drilling (ERD) has become one of the most significant technological advancements in modern drilling engineering, enabling hydrocarbon reservoirs located at considerable horizontal distances from the drilling location to be accessed from a single surface site. The increasing demand for cost-effective reservoir development, combined with environmental considerations and the need to maximize recovery from mature fields, has encouraged the petroleum industry to adopt ERD solutions as an alternative to conventional field development approaches. In parallel, the existence of a large number of mature and highly deviated wells worldwide presents an opportunity to repurpose existing infrastructure through well conversion strategies rather than constructing entirely new wellbores. Such an approach can substantially reduce capital expenditure, minimize environmental impact, and accelerate field development. However, the conversion of an existing highly deviated J-shape well into an Extended Reach Well (ERW) introduces significant technical challenges related to well trajectory design, mechanical limitations, hydraulic performance, hole cleaning, and Equivalent Circulating Density (ECD) management.

This doctoral research investigates the technical feasibility of converting an existing highly deviated J-shape well into an Extended Reach Well through an integrated methodology that combines trajectory optimization, torque and drag analysis, hydraulic simulation, ECD management, mathematical modeling, statistical analysis, and Artificial Intelligence (AI)-assisted predictive techniques. The study uses the IQ-KRI-78 well, located in northern Iraq, as a representative field case. The selected well was originally drilled in 2010 to a measured depth of approximately 2,200 meters with a final inclination of 72° and a constant azimuth of 90°, making it a suitable candidate for conversion into an ERD well. The well architecture includes 20-inch casing set at 500 meters, 13-3/8-inch casing at 1,600 meters, and 9-5/8-inch production casing landed at 2,200 meters. The proposed design extends the well to a total measured depth of 6,000 meters by gradually building inclination from 72° to 90° over 300 meters with a maximum dogleg severity of 1.83° per 30 meters, followed by a horizontal tangent section holding 90° inclination to the target depth, while preserving the existing casing architecture and surface location. The achieved step-out ratio is 2.97, meaning for every meter of vertical depth, the well extends approximately 2.97 meters horizontally at total depth, formally meeting ERD criteria.

The research was structured around three interconnected phases. The first phase focused on well trajectory optimization. Existing well survey data, casing constraints, and directional drilling requirements were analyzed to redesign the well profile while minimizing dogleg severity, reducing curvature-induced friction, and maintaining mechanical integrity. Particular emphasis was placed on achieving a smooth transition from the existing J-shape geometry to a horizontal ERD configuration capable of maximizing horizontal displacement while remaining within

operational drilling limits. A thorough well profile selection study was conducted, comparing various trajectory types including Type I (build-and-hold), Type III (S-shaped), and Type IV (horizontal). The analysis concluded that Type IV horizontal trajectories provide the most mechanically efficient configuration for ERD applications, while S-shaped and high-dogleg profiles are unsuitable due to excessive friction and cumulative curvature effects. The optimized trajectory was subsequently evaluated against established ERD design criteria and benchmarked against successful extended-reach drilling applications reported in the literature.

The second phase addressed the mechanical feasibility of the proposed conversion through comprehensive torque and drag (T&D) analysis. Detailed simulations were performed using the soft-string model based on the seminal work of Johancsik, Friesen, and Dawson, with force balance equations incorporating gravitational and bending components. The analysis considered multiple friction-factor scenarios ranging from 0.2 to 0.5, drillstring configurations, and Bottom Hole Assembly (BHA) designs, including Positive Displacement Motor (PDM) for the build section from 2,200 to 2,500 meters and Rotary Steerable System (RSS) for the extended lateral section from 2,500 to 6,000 meters. Hook load, surface torque, axial loading, buckling tendency, and drag forces were evaluated throughout the proposed drilling interval. The soft-string model calculations indicated static hook load of 112,500 pounds, maximum hook load during pull out of hole of 213,930 pounds, off-bottom torque of 45,600 foot-pounds, and maximum surface torque of 51,000 foot-pounds. Comparative analysis revealed that RSS reduces torque by approximately 44% in the lateral section compared to conventional PDM operation, with torque transfer efficiency increasing from approximately 35% for PDM to approximately 70% for RSS. The RSS BHA exhibited lower frictional drag, balanced stress utilization with Von Mises stress of approximately 35,800 psi, and very low buckling risk. The Motor BHA, though mechanically simpler, exhibited higher frictional energy dissipation during sliding, reflected by increased side-forces and torque losses. Sensitivity analyses demonstrated the strong influence of friction reduction, trajectory smoothness, and BHA selection on achievable well reach. Results indicated that the optimized trajectory could be drilled without exceeding rig mechanical limitations, while RSS-based drilling provided superior weight transfer, reduced frictional loading, and improved operational efficiency compared with conventional motor-driven directional drilling.

The third phase focused on hydraulic performance and Equivalent Circulating Density management, which represents one of the most critical constraints in extended-reach drilling operations. Hydraulic simulations were conducted for both conventional drilling and Managed Pressure Drilling (MPD) scenarios using different mud weights (12 to 13 ppg), flow rates (400 to 600 GPM), and drilling conditions at critical depths of 2,500 meters and 6,000 meters measured depth. The investigation included evaluation of annular pressure losses, surge and swab effects, hole-cleaning performance, cuttings transport efficiency, and ECD variation throughout the well profile. At 2,500 meters measured depth with MPD and 12 ppg mud weight, ECD was maintained at 15.00 ppg under controlled conditions compared to 16.50 ppg estimated for conventional drilling. At total depth of 6,000 meters measured depth with MPD and optimized parameters including mud weight of 12.6 ppg, flow rate of 580 GPM, rotary speed of 160 RPM, and rate of penetration of 18.5 meters per hour, ECD was predicted at 14.45 ppg, which remains below the fracture gradient of 18.5 ppg. The analysis confirmed that MPD offers superior dynamic control during connections and tripping, with surge and swab pressures effectively managed through surface backpressure application. The maximum recommended tripping speed for rotating control device bearing is 18.29 meters per minute (60 feet per minute). The results demonstrated that careful optimization of drilling-fluid properties and circulation parameters allows ECD to remain within the acceptable pore-pressure and fracture-gradient window. Furthermore, MPD techniques were shown to provide additional operational flexibility and enhanced pressure control, particularly in the long horizontal section where hydraulic challenges become increasingly significant.

A major contribution of this thesis is the development and integration of advanced mathematical, statistical, and Artificial Intelligence-based models for drilling optimization. Novel mathematical formulations were proposed for torque and drag calculations based on the soft-string model, including the normal force formulation combining gravitational and bending components. For ECD prediction, comprehensive models accounting for cuttings concentration, temperature effects, and wellbore inclination were developed. For surge and swab pressure estimation under ERD conditions, formulations for both laminar and turbulent flow regimes with Newtonian and non-Newtonian fluid models were presented. These deterministic models were complemented by statistical approaches and machine-learning algorithms designed to improve prediction accuracy and support decision-making, including Multi-Task Learning Neural Networks, Gradient Boosting Regression, Random Forest Regression, and Long Short-Term Memory networks. A Physics-Informed Hybrid Model was introduced that integrates classical physical equations with statistical corrections, ensuring physical consistency while learning complex real-world adjustments. Explainable Artificial Intelligence methods, including SHAP (SHapley Additive Explanations) analysis, were employed to identify the relative importance of operational and geometric parameters affecting drilling performance, revealing that measured depth and mud weight account for approximately 70% of the influence on ECD at 6,000 meters. Additionally, a digital-twin concept was developed to simulate drilling conditions and evaluate alternative operational scenarios before field implementation. Multi-well comparative analyses involving international ERD reference wells from Sakhalin, Wytch Farm, and Abu Dhabi further validated the proposed methodology and demonstrated its applicability beyond the selected case study, with all AI models achieving R-squared scores above 0.98.

The findings of this research confirm that the conversion of the IQ-KRI-78 well from a highly deviated J-shape profile into an Extended Reach Well is technically feasible when mechanical, hydraulic, and operational parameters are optimized through an integrated engineering framework. The study demonstrates that successful ERD conversion requires simultaneous consideration of trajectory design, torque and drag management, ECD control, drilling-fluid optimization, and advanced digital technologies. The developed methodology provides a structured decision-support framework that can be applied to future brownfield drilling projects seeking to maximize resource recovery while minimizing environmental footprint and development costs, with estimated cost reductions of 25 to 40 percent compared to new well construction.

From a scientific perspective, this research contributes to the advancement of drilling engineering by bridging the gap between traditional deterministic well-planning methods and emerging AI-driven optimization approaches. The theoretical contributions include the derivation of stability criteria for trajectory perturbations in anisotropic stress fields and proof of convergence for modified chaotic particle swarm optimization algorithms under ERD constraints. From an industrial perspective, the proposed framework offers practical guidance for field engineers, drilling planners, and operators evaluating the feasibility of converting mature wells into extended-reach assets. The integration of predictive analytics, digital-twin technology, and physics-based engineering models represents a step toward the future implementation of intelligent drilling systems capable of enhancing operational efficiency, reducing drilling risks, and supporting sustainable hydrocarbon development.

Keywords: Extended Reach Drilling (ERD), Extended Reach Well (ERW), J-shape well conversion, well trajectory optimization, torque and drag, equivalent circulating density (ECD), managed pressure drilling (MPD), drilling hydraulics, artificial intelligence, machine learning, SHAP analysis, digital twin, drilling optimization, Rotary Steerable System (RSS), Positive Displacement Motor (PDM), soft-string model, non-Newtonian fluid rheology, surge and swab pressures, brownfield development, petroleum engineering.