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Application of Petroleum Information Technology in Oil and Gas Drilling Engineering

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Abstract: As oil and gas resources gradually become depleted, drilling engineering is expanding into deeper terrestrial layers and deep-sea areas. These regions often have geological environments characterized by extreme and complex conditions such as high temperatures and high pressures, posing significant challenges to traditional drilling technologies. Currently, artificial intelligence and big data technologies are driving technological innovation in the field of oil and gas drilling, further promoting the automation of drilling operations management and the intelligentization of decision-making processes. Taking into account the research advancements both domestically and internationally, as well as actual engineering needs, this paper provides an in-depth analysis and summary of intelligent extraction technologies and intelligent drilling processes within the scope of smart drilling technology. Additionally, it offers a forward-looking perspective on the future development trends of intelligent drilling technology, aiming to provide robust support for the intelligent upgrading of the oil and gas industry.

Keywords: Drilling Engineering; Intelligent Extraction Technology; Intelligent Drilling Process; Artificial Intelligence.

1. Introduction

At present, oil and gas exploration and development are undergoing a significant transformation. With the continuous deepening of exploration activities, many mature oilfields are entering the middle and late stages characterized by high water content [1]. However, as a core component of oil and gas exploration and development, drilling is moving towards deeper and deeper water layers. The complex geological conditions in these deeper layers highlight significant shortcomings in traditional drilling technologies [2]related to extraction and processing. When encountering hard rock formations, the limited capabilities of some technicians, combined with the high costs of drilling, make extraction work even more challenging. In particular, traditional technical methods lack precision in well positioning and have low production efficiency, making it difficult to meet high-demand requirements [3]. This directly leads to crude oil production failing to meet expected targets, severely affecting the stability and continuity of oil production. Thus, the development of a new generation of transformative drilling technologies is critical.

In petroleum drilling operations, the effective use of modern information technology can significantly improve production efficiency, enhance the quality of petroleum products, and reduce operational costs. Given that drilling operations primarily occur underground, they are characterized by unpredictability and a high degree of concealment, along with highly complex processes and massive amounts of information involved [4]. Continuing to use traditional techniques for quantification and data reading will severely impact the efficiency and quality of data collection. As the oil and gas drilling industry rapidly transitions towards digitization and intelligence, the application of information technology in drilling engineering is growing rapidly. These new technologies optimize drilling processes through machine learning, natural language processing, and computer vision, providing a solid decision-making foundation from the perspective of information data, and offering intelligent support for drilling operation efficiency [5].

1.1. The Needs of Drilling Technology for Petroleum Information Technology

(1)Need for Underground Information Accuracy. In the field of oil drilling, the operating environment is complex and constantly changing, with research focusing deep within geological formations. The entire process relies heavily on accurate underground information gathering, which is then combined with professional knowledge and experience for geological analysis. This approach is essential to accurately depict the underground environment, guiding the design and implementation of drilling operations. Given the complexity and vast amount of information related to the underground environment, any errors in judgment can lead to strategic drilling mistakes, resulting in high cost losses and resource wastage.

(2)Urgent Need for Real-Time Information Transmission. Drilling operations take place in a rapidly changing downhole environment, with fluctuating parameters such as rock formation structures and pressure conditions. These dynamic changes directly impact the smooth progress of drilling operations. If information transmission is delayed or distorted, it could lead to inaccuracies in operational positioning and delays in project timelines. Therefore, capturing and transmitting real-time information about changes in downhole conditions is crucial for technical personnel. It enables them to respond swiftly, adjust drilling strategies, and modify operational protocols, ensuring precise and efficient construction.

(3)Urgent Need for Transition to Information-Based Management. Drilling operations typically involve dispersed teams, high mobility, and harsh natural environments. As drilling projects continue to expand in scale, traditional management models show significant disadvantages. Modern information technology brings new transformations to the drilling industry by establishing an information-based management system for drilling engineering. This system enables detailed monitoring and management of the entire drilling process, covering functions such as equipment condition monitoring, real-time tracking of construction progress, and safety hazard warnings. It not only improves the efficiency of drilling operations but also effectively reduces safety risks, providing solid assurance for the smooth operation of drilling projects.

2. Intelligent Extraction Technology

2.1. Intelligent Drill Bit Technology

The drill bit, a critical component of drilling equipment, is designed to break rock formations and create the wellbore. Currently, roller cone bits and PDC (Polycrystalline Diamond Compact) bits are widely used for rock breaking in exploration and development. However, they also face challenges such as complex manufacturing processes and susceptibility to structural damage. Intelligent drill bit technology, by integrating advanced sensors and control units, can monitor reservoir properties and downhole geological conditions in real time and automatically adapt to formation conditions. This extends the bit's lifespan and improves drilling efficiency.

Shaohe Zhang [6] utilized 3D printing technology in the manufacturing process of PDC bit molds, demonstrating through experiments a significant improvement in the rock-breaking efficiency of the new bits. Huang Zhe [7] developed a central modular stress measurement scheme that employs rigid connections and designed a prismatic motion measurement array and its data processing method, successfully producing a prototype of an intelligent drill bit. Experimental results confirmed the effectiveness of this technology and method. Baker Hughes' TerrAdapt adaptive bit uses feedback from sensors to adjust the cutting depth of the bit based on the underground rock formation structure and the predetermined target location, thereby reducing stick-slip phenomena during the drilling process. In Kuwait, the first use of an adaptive bit equipped with a rotary steering system effectively reduced vibration during drilling and successfully increased the average rate of penetration (ROP) in the oilfield. Halliburton's latest deep-cut roller element bit technology leverages the wear-resistant and impact-resistant properties of roller elements to significantly reduce friction heat and resistance during drilling [8]. Overall, given that drilling operations are typically conducted under harsh conditions such as high pressure and high temperature, intelligent drill bit technology still requires further innovation and improvement to enhance mechanical strength and maintainability.

2.2. Intelligent Drilling Rig Technology

In the process of oil exploration, the drilling rig drives the drill string to penetrate underground rock formations to reach a predetermined depth, allowing oil and gas extraction equipment to extract petroleum and natural gas. The oil drilling rig is the core equipment of drilling operations, comprising eight major systems, including the hoisting system, transmission system, and drilling fluid circulation system. Traditional rigs require manual control and are associated with high risks. However, with technological advancements, intelligent drilling rigs have integrated automated control systems, allowing for real-time remote monitoring of downhole working conditions and enabling precise parameter control of the rig [9].

Korry Machinery's 9000m AC variable frequency electric drive rig with a winch hoisting method introduces features such as dual-powered mouse holes, iron roughnecks, vertical pipe handlers, and automated pipe handling systems on the second floor. Baoji Petroleum Machinery designed a ground remote-controlled hydraulic cylinder lifting system and developed a 7000m automated rig, which has been deployed in demonstration areas, significantly increasing lifting speed and drilling efficiency. Herrick's automated rig employs a hydraulic hoisting system and introduces a horizontal-vertical tubular handling system. West's continuous-motion intelligent rig utilizes a rack-and-pinion system with dual hoisting systems, allowing continuous drilling without stopping pumps or drilling while connecting single joints, thereby enhancing work efficiency. Nabor's fully automated land drilling rig, operating without manual intervention, achieved the first fully automated drilling operation in the Permian Basin of the United States, reaching a total well depth of 6,071m. Overall, although current intelligent drilling rig technology has achieved certain advancements, further research and development are needed in areas such as intelligent analysis, variable frequency control, and tubular handling, in conjunction with modern cutting-edge technologies.

2.3. Intelligent Drill Pipe Technology

Drill pipes connect surface drilling rigs with equipment like drill bits located at the bottom of the wellbore. They primarily transmit torque and drilling pressure, guiding the drill bit through the formation. While traditional drill pipes play a crucial role in drilling operations, they have limitations such as the inability to monitor downhole conditions in real-time, limited data transmission capabilities, and poor adaptability to complex formations. With the continuous development of information technology, intelligent drill pipes [10] are gradually overcoming these challenges, bringing significant breakthroughs to drilling technology.

Currently, Hilong Petroleum Tubular Goods Research Institute has developed intelligent drill pipes capable of wired power transmission of 1 kW from the surface to the downhole, enabling real-time control of downhole drilling progress. The American company NOV has developed a telemetry drill pipe system with low communication power requirements that can transmit high-frequency signals in the MHz range without significant attenuation. Baker Hughes has introduced an intelligent drill pipe induction joint, which embeds a ring antenna at each end of adjacent drill pipe joints, utilizing near-field transmission technology to transmit data between drill pipes. China National Petroleum Corporation has developed a high-speed data transmission drill pipe that uses key magnetic coupling wired technology, achieving bidirectional communication speeds of up to 10^5 bps. Fiberspar has developed an intelligent coiled tubing with built-in power and signal transmission lines, allowing simultaneous data transmission and power supply to downhole equipment. Overall, intelligent drill pipe technology overcomes the limitations of data transmission efficiency in traditional drilling, effectively enhancing the efficiency of drilling operations.

2.4. Intelligent Drilling System

An intelligent drilling system integrates various cutting-edge technologies such as big data, artificial intelligence, the Internet of Things (IoT), and cloud computing to improve the efficiency and safety of drilling operations. By providing automated computation, analysis, and real-time monitoring at various stages of drilling, it optimizes the drilling process, reduces costs, and increases oil and gas well production and recovery rates [11, 12, 13].

British Petroleum (BP) combines digital twin technology with artificial intelligence to determine the optimal speed and direction of drilling operations, optimize the usage of water, chemicals, and other resources, and reduce operational time by nearly 50%, significantly enhancing drilling efficiency. Baker Hughes' ScadaDrill remote control platform offers capabilities such as remote data transmission, intelligent data analysis, and risk assessment. It collects historical drilling data, uses machine learning for autonomous learning, simulates drilling operations, and optimizes drilling parameters accordingly. Shell's intelligent directional drilling analysis system employs advanced electronic sensing technology and high-speed telemetry to conduct intelligent analysis and decision-making throughout the well construction lifecycle, thereby improving drilling accuracy, reducing well duration, and achieving desired drilling outcomes. Schlumberger's Manara intelligent completion system integrates selective, real-time flow measurement, and electronic control with production and reservoir management systems, enabling damaged zones to produce oil. By managing flow rates during operations, production increased by 40%. Norway's eDrilling company has launched an intelligent platform that features automated drilling control, drilling design, and optimization, integrating real-time drilling simulation, 3D visualization, and remote control to achieve safe, efficient, and economical drilling through risk prevention and drilling optimization. Sinopec Research Institute has developed an intelligent drilling platform based on big data and artificial intelligence. This platform supports the loading, parsing, and customization of drilling algorithms, promoting the advancement of drilling operations towards high efficiency and intelligence. Shengli Oilfield has developed an intelligent drilling fluid monitoring system that uses artificial intelligence to achieve intelligent analysis and processing of drilling fluids and automate operations during the construction process, thereby improving work efficiency and operational safety. As the complexity of drilling environments increases and safety and environmental protection standards are heightened, the application of intelligent drilling systems is expected to further expand.

3. Intelligent Drilling Techniques

3.1. Intelligent Wellbore Trajectory Optimization Technology

Optimizing wellbore trajectories is critical for improving drilling efficiency and safety, handling complex geological conditions, enhancing oil and gas recovery rates, and advancing technological progress and industry development.

Reza [14] proposed a combination of PSO-DIRECT+FMM to facilitate the optimization of wellbore trajectory parameters in vertical, deviated, and horizontal wells, applying it in actual field cases. The results showed that using FMM as an auxiliary function for the reservoir simulator is better than completely replacing the reservoir simulator. Kallol [15] proposed an improved multi-objective cellular spotted hyena algorithm to optimize the true measured depth, well profile energy, and torque. Compared to other algorithms, this method shows significant improvements in the better distribution of non-dominated solutions, enhanced search capability, fewer isolated minima, and a superior Pareto optimal front. Xiaoping [16] introduced an intelligent optimization numerical model for well trajectory and pad deployment during cluster drilling. This model uses the K-means dynamic clustering algorithm to optimize pad locations and divide target cells into different pads simultaneously to minimize costs. The model can automatically optimize the location, scale, and number of well pads, as well as well types and trajectories. Antonio [17] proposed a Cellular Automata-Based Multi-Objective Hybrid Grey Wolf Optimization and Particle Swarm Optimization Algorithm for Wellbore Trajectory Optimization. This algorithm not only enhances the exploration capabilities of the original algorithm but also addresses the optimization of three objectives involving 17 tuning variables. Current wellbore trajectory control technologies have yet to systematically study the diverse data from geological and engineering fields. Presently, challenges remain in real-time data updating and efficiently transmitting drilling information.

3.2. Intelligent Drilling Rate Optimization Technology

Traditional mechanical rate of penetration (ROP) predictions is mostly conducted post-drilling, resulting in low prediction efficiency and accuracy, and limited adaptability to different formations. With technological advancements, intelligent drilling rate optimization has become a key technique to improve drilling performance, reduce costs, and enhance operational quality.

Neng Zhang [18] developed a PSO-BP neural network model for ROP prediction, using the PSO algorithm to optimize the initial weights and thresholds of the BP neural network, achieving accurate ROP predictions. Yunwei Gao [19] used the Local Outlier Factor detection algorithm for data preprocessing and established a mechanical ROP prediction model based on Stacking ensemble learning. Results showed that the predicted mechanical ROP matched the actual ROP, and the model's performance was stable. Yi Feng [20] proposed a deep sequence-based ROP prediction method using Long Short-Term Memory (LSTM). This method uses the Pearson correlation coefficient to measure correlations among features, addressing inefficiencies and low prediction accuracy in handling complex formation problems with previous methods. Ren [21] introduced an adaptive feature optimization ROP prediction method based on real-time data, which significantly improved the accuracy of ROP prediction models compared to non-adaptive methods. Overall, although intelligent drilling rate optimization technology has achieved some success, challenges remain in data acquisition and processing, coordinated hardware-software control, and the adaptability to varied and complex application scenarios.

3.3. Intelligent Monitoring and Decision-Making Technology

In the complex and ever-changing field of drilling engineering, traditional decision-making heavily relies on the expertise and experience of decision-makers. However, with the advancement of intelligent monitoring and decision-making technologies, these technologies can not only significantly enhance the responsiveness of on-site decisions but also provide more scientific and optimized decision-making suggestions through accurate data analysis and intelligent algorithms.

Kai Xu [22] summarized and found that machine learning technology shows great potential in downhole control of drill string conditions, risk monitoring and assessment, and decision support. This study provides strong support for technological upgrades and transformation in the oil and gas industry. Sinopec Jingwei Co., Ltd. [23] developed an integrated decision support platform for drilling sites, which shows broad application prospects in oilfields through real-time data aggregation, system integration, and application empowerment. Jingjia Li [24] developed the Well Lift production analysis and optimization decision system for oil and gas wells. This system meets the needs of drilling engineering analysis and design by studying the coupling relationships among multiphase flow in wellbores, reservoir inflow dynamics, and other factors. Adlakha [25] focused on formation and wellbore trajectory data for wells in regions like the North Sea. Using convolutional neural networks, they accurately calculated the similarity between different wells. Compared to traditional methods relying on neighboring well data, this method significantly expands the reference range of similar well data, helping to improve the scientific and accuracy of decision-making. Based on these studies, intelligent drilling decision support systems have made progress in improving operational efficiency, simulation prediction, and risk warning. Future research should further explore the integration of big data, high-end transmission devices and precise analytical processes to develop an integrated geological-engineering drilling management platform.

4. Development Directions and Conclusion

In recent years, with the rapid development of big data technology, oilfield informatization technology has reached a new turning point. The deep integration of information technology not only accelerates drilling efficiency but also significantly enhances the recovery rate of oil and gas resources, opening up vast applications and development opportunities in the petroleum field. The continuous advancement of intelligent drilling technology will necessitate in-depth research into a series of key foundational theories and core technologies, injecting new momentum of intelligent technology into the drilling field. This is mainly reflected in the following three aspects:

(1)Unified System Architecture and Data Standards: Currently, the oil and gas sector lacks an organization to coordinate and promote the development of intelligent drilling technologies. Therefore, establishing a standardized and normative system for intelligent drilling technology is crucial to allow seamless data communication across different scenarios, ensuring interoperability and operability between systems.

(2)Establishing Comprehensive Intelligent Monitoring, Diagnosis, and Decision-Making Systems for Complex Oil and Gas Wells: It is important to build a multi-source heterogeneous information platform, continuously research and improve algorithm models, and develop intelligent control technologies for real-time analysis of drilling parameters. This would facilitate intelligent dynamic drilling optimization solutions under complex and harsh working conditions.

(3)Collaborative Innovation: Integrating knowledge from petroleum engineering, automation, applied mathematics, and other disciplines will drive breakthroughs in intelligent drilling technology. The goal is to develop integrated technologies for advanced detection and intelligent characterization of complex formations.

In summary, enhancing the application scale of information technology in oil exploration and development and further promoting the comprehensive development of intelligent drilling technology will provide intelligent decision support for the development of unconventional, low-permeability, and deepwater oil and gas resources.

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