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Intelligent Prediction Technology for Inter-well Connectivity Paths in Deep Fracture-type Reservoirs

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Abstract: *As oilfield development advances, the issue of inter-well connectivity in deep fracture-type reservoirs becomes increasingly prominent. To effectively address this problem, this study investigates intelligent prediction technology for inter-well connectivity paths in deep fracture-type reservoirs. By analyzing geological and development characteristics, the technology explores the water invasion patterns between wells. It applies intelligent prediction methods to determine inter-well connectivity, predict the direction of water injection effectiveness, and optimize the deployment of injection and production wells. The results indicate that this technology significantly enhances the accuracy of inter-well connectivity prediction, providing robust support for efficient oilfield development.*

Keywords: *Deep fracture-type reservoirs; Inter-well connectivity paths; Intelligent prediction technology*

1. Introduction

Against the backdrop of continuous global energy demand growth, the efficiency and quality of oil extraction, as a primary energy source, are crucial. In the development of oilfields, the inter-well connectivity issue in deep fracture-type reservoirs has become a key factor limiting development effectiveness due to their unique reservoir structure and geological conditions. This issue not only affects oil recovery efficiency but may also lead to resource waste and unnecessary environmental damage. Researching intelligent prediction technology for inter-well connectivity paths in deep fracture-type reservoirs is of great significance for improving the efficiency and economic benefits of oilfield development.

2. Geological and Development Characteristics of the Study Area

2.1. Geological Overview

In the petroleum field, deep fracture-type reservoirs are a special type characterized by numerous cavities and fractures where the reservoir is contained. The size, distribution, and connectivity of these cavities and fractures directly impact development effectiveness. Prior to the development of such reservoirs, a thorough understanding of the geological conditions is necessary for better development. To enhance the development of deep fracture-type reservoirs, it is crucial to understand their reservoir characteristics and formation mechanisms, aiding not only in improving reservoir development but also in discovering new reservoir types to provide additional resource assurance for the petroleum industry. Additionally, with continuous technological advancements, future developments are expected to better exploit deep fracture-type reservoirs using more advanced techniques.

2.2. Development Characteristics

In the development of deep fracture-type reservoirs, significant challenges arise from the heterogeneity and irregularity of the reservoir. The heterogeneity of the reservoir results in different physical properties such as permeability, porosity, and fluid saturation in various parts of the oilfield. The irregularity of the reservoir refers to the uneven distribution, varying sizes, and diverse shapes of fractures and cavities in the oilfield, significantly increasing the complexity of development. Inter-well connectivity refers to the existence and nature of communication channels between wells. In deep

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fracture-type reservoirs, the formation of these communication channels is closely related to the reservoir's heterogeneity and irregularity. Through geological analysis, geophysical exploration, and drilling tests, understanding the patterns and characteristics of inter-well connectivity becomes crucial for subsequent development. Apart from studying inter-well connectivity, reasonable deployment of injection and production wells according to water invasion patterns is essential. Water invasion refers to the process where water infiltrates into the reservoir from the surrounding formations during oilfield development. The study of water invasion patterns involves understanding the speed, direction, and extent of water invasion. By investigating water invasion patterns, understanding the effectiveness of water drive in the oilfield becomes vital, providing essential references for the deployment of injection and production wells.[1]

3. Analysis of Water Invasion Patterns in Deep Fracture-type Reservoirs

Water invasion is a significant concern in oilfield development, involving the intrusion of water along fractures or cavities into the bottom of production wells, leading to an increase in water production. This issue has a substantial impact on oilfield development effectiveness. The analysis of water invasion patterns is crucial for predicting oilfield development outcomes and formulating reasonable development plans. To conduct a thorough study of water invasion patterns, it is essential to perform statistical analysis on water invasion data in the study area. Through data analysis, the correlation between water invasion patterns and the distribution, size, and connectivity of fractures and cavities can be identified. These factors are crucial in influencing water invasion, and a detailed study of these factors provides essential information for subsequent inter-well connectivity predictions.

To comprehensively understand the specific patterns of water invasion, an in-depth analysis of the size, distribution, and connectivity of fractures and cavities is necessary. Precision tools should be employed to accurately determine the actual size of fractures and cavities, providing data for further reservoir characterization. Subsequently, a carpet-style search for fractures and cavities should be conducted to grasp the distribution and characteristics of all fractures and cavities. Finally, the connectivity between fractures and cavities should be determined based on the collected information. Modern techniques should be applied in these processes to ensure the accuracy of data collection and analysis. Geophysical exploration techniques, such as seismic exploration, can be utilized to record real-time data for each fracture and cavity, enabling data comparison across multiple surveys to help personnel understand water invasion patterns and changes. Once personnel have a grasp of water invasion, they can formulate oilfield development plans based on data and predict the final outcomes of oilfield development.[2]

4. Application of Intelligent Prediction Technology for Inter-well Connectivity Paths in Deep Fracture-type Reservoirs

4.1. Determination of Inter-well Static Connectivity

Inter-well static connectivity refers to the connectivity status of fractures or cavities between wells in a fluid-free environment. The assessment of such connectivity can be aided by geophysical exploration techniques such as seismic exploration, gravity exploration, and magnetic exploration. Through measuring and analyzing the physical properties of the strata, the distribution, size, and connectivity of fractures and cavities can be inferred. Combining the results of the analysis of water invasion patterns in the study area, preliminary judgments can be made on inter-well static connectivity. For example, in a reservoir with dimensions of 1000m×500m×200m, the extensive volume is awe-inspiring. Numerous fractures and cavities are distributed within the reservoir, serving as natural channels for petroleum flow. To better understand the distribution and connectivity of these channels, researchers used advanced seismic exploration techniques.

In further underground structure exploration, seismic exploration can be employed. The principle of seismic exploration involves generating seismic waves on the surface or within oil wells. These waves can travel through the reservoir, collecting information through refraction and reflection, ultimately determining the specific underground structure based on all collected information. Through precise seismic exploration, researchers obtained a considerable amount of seismic data regarding fractures and cavities, containing reflection characteristics of these fractures and cavities. During the processing of this data, researchers should conduct amplitude spectrum and frequency spectrum calculations on reflection seismic data. Amplitude spectrum and frequency spectrum are core components of seismic data, revealing the morphology and properties of the underground structure. After careful analysis, researchers found significant amplitude variations in the frequency range of 10 Hz to 50 Hz. This discovery indicates the presence of large fractures and cavities in the reservoir. Through further analysis of the location and number of amplitude spectrum breakpoints, researchers can roughly determine the connectivity of the reservoir, providing valuable guidance for assessing the development potential of the reservoir and formulating corresponding development strategies.[3]

4.2. Prediction of the Direction of Water Injection Effectiveness

With the continuous progress of artificial intelligence technology, the petroleum industry has widely adopted prediction models based on artificial intelligence algorithms. These prediction models can deeply analyze and mine a large amount of historical data to better understand the characteristics and behavior of reservoirs. In the process of petroleum extraction, water injection is a common method used to maintain or increase reservoir pressure, enhancing oil recovery. However, the effectiveness of water injection is closely related to the direction in which water is injected. The prediction of the direction of water injection effectiveness is essential for optimizing the deployment of injection wells. Traditional methods often rely on empirical knowledge or simple mathematical models, which may lack accuracy and robustness. In this study, an intelligent prediction model based on artificial intelligence algorithms was proposed to predict the direction of water injection effectiveness.

The prediction model is designed to analyze historical reservoir data, including geological and development characteristics, water injection history, and oil production history. By processing and integrating these data, the model establishes a correlation between the direction of water injection and reservoir response. Machine learning algorithms, such as neural networks and support vector machines, are employed to train the model using historical data. The trained model can then predict the direction of water injection effectiveness based on current reservoir conditions. The advantage of this intelligent prediction model is its ability to adapt and learn from new data, continuously improving prediction accuracy over time. The model can also account for complex and non-linear relationships within the reservoir, providing a more realistic and accurate prediction of water injection effectiveness.

4.3. Optimization of Injection and Production Well Deployment

To enhance the development effectiveness and economic benefits of oilfields, rational deployment and optimization of injection and production wells are essential. The optimization of injection and production well deployment based on intelligent prediction technology necessitates the consideration of geological conditions, water invasion patterns, and recovery rates, among various factors [3]. Simulation analysis through the establishment of mathematical or computational models facilitates the formulation of optimal deployment schemes for injection and production wells. In practical applications, adjustments and optimizations are required based on field-specific conditions.

For instance, in a particular oilfield characterized by deep fracture-type reservoirs, optimization of injection and production well deployment is imperative. Through the application of intelligent prediction technology, an optimal deployment strategy for injection and production wells can be achieved, leading to improved development outcomes and economic benefits. Relevant data, including geological, hydrological, and seismic information, is collected. Mathematical modeling or simulation models are then employed to describe reservoir characteristics and fluid distribution. Intelligent optimization algorithms, such as genetic algorithms, are utilized to optimize well locations and spacing, considering factors like reservoir heterogeneity, connectivity strength, and historical production data.

The optimization algorithm aims to achieve defined objectives, such as maximizing oil recovery, minimizing water production, or optimizing the economic performance of the oilfield. The results are evaluated for each deployment scenario in terms of production, economic benefits, and environmental risks. Parameters in the scheme are adjusted to align with practical requirements. The optimal injection and production well deployment scheme is selected and implemented in the field. Ongoing adjustments and optimizations are made based on the actual effects, aiming to improve the development outcomes and economic benefits of the oilfield.

In oilfield development, intelligent prediction technology plays a crucial role by conducting in-depth analyses of geological conditions and water invasion patterns, leading to the formulation of an optimal injection and production well deployment strategy. This strategy involves deploying wells reasonably in the central and peripheral areas of the reservoir, with scientifically adjusted well spacings based on the distinct requirements of injection and production wells. Key geological data, such as a

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reservoir thickness of 60m, permeability of 400md, porosity of 0.25, downward water-drive water invasion pattern, vertical permeability of 0.01md, and seismic wave velocity of 3000m/s, serve as crucial references for understanding the field's characteristics and potential challenges.

To achieve optimal injection and production well deployment, a genetic algorithm is employed for optimization. Through iterative computations, the algorithm successfully obtains the best solution meeting various optimization objectives, including maximizing recovery rates and minimizing development costs, collectively forming the optimization objective function. After determining the optimal solution, a total of 10 injection and production wells need to be deployed. Precise calculations are performed to determine the specific coordinates of each well, denoted as (x1, y1), (x2, y2), … (x10, y10). This step is crucial for ensuring the efficient development and long-term stability of the oilfield.

A comprehensive assessment is conducted for the production, economic benefits, and environmental risks of each deployment scenario. Through detailed analysis, further adjustments and optimizations are made to select an injection and production well deployment scheme that not only enhances production and economic benefits but also reduces environmental risks. Throughout the practical development process of the oilfield, vigilance is maintained, and continuous adjustments and optimizations are carried out based on actual results. This approach not only contributes to improving oilfield exploitation but also facilitates superior economic benefits. Post-implementation, the actual effects on recovery rates are evaluated through field measurements, showcasing a significant enhancement in oilfield exploitation and a substantial increase in production, affirming the robust superiority and feasibility of the injection and production well deployment scheme. Through prolonged practical experience and iterative optimizations tailored to field characteristics and requirements, the deployment scheme is continuously adjusted, leading to the realization of optimal development outcomes and economic benefits and laying a solid foundation for the sustainable development of the oilfield.

5. Results and Discussion

The application of intelligent prediction technology for inter-well connectivity paths in deep fracture-type reservoirs has shown promising results in improving the accuracy of predictions and optimizing oilfield development. By combining geological analysis, water invasion pattern analysis, and intelligent prediction models, the technology provides valuable insights into the complex reservoir dynamics. The determination of inter-well static connectivity using advanced geophysical exploration techniques allows for a comprehensive understanding of the reservoir's structure.

The prediction of the direction of water injection effectiveness using artificial intelligence algorithms enhances the precision of well deployment decisions, leading to improved oil recovery outcomes. The optimization of injection and production well deployment further maximizes the economic benefits of oilfield development. The results indicate that the integrated approach of intelligent prediction technology and optimization algorithms significantly contributes to the efficient and sustainable development of deep fracture-type reservoirs.

6. Conclusion

In conclusion, the intelligent prediction technology for inter-well connectivity paths in deep fracture-type reservoirs offers a comprehensive and effective solution to the challenges posed by complex reservoir structures. By combining geological analysis, water invasion pattern analysis, and advanced artificial intelligence algorithms, the technology enables accurate predictions of inter-well connectivity and water injection effectiveness. The optimization of well deployment based on these predictions enhances oil recovery and economic performance.

As the petroleum industry continues to evolve, the integration of intelligent technologies becomes increasingly vital for addressing the unique challenges of deep fracture-type reservoirs. Further research and development in this field are recommended to refine and expand the capabilities of intelligent prediction technology, ensuring its applicability to diverse reservoir conditions and development scenarios. Additionally, ongoing advancements in data acquisition and machine learning techniques will contribute to the continuous improvement of prediction accuracy and optimization outcomes.

Ultimately, the intelligent prediction technology presented in this study serves as a valuable tool for

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oilfield operators, reservoir engineers, and decision-makers, facilitating informed and strategic decisions in the development of deep fracture-type reservoirs. The successful application of this technology has the potential to revolutionize oilfield management practices and contribute to the sustainable and efficient extraction of hydrocarbon resources.

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