Research on Methods for Petroleum Geological Exploration and Reservoir Evaluation

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Abstract

Petroleum geological exploration and reservoir evaluation technologies are pivotal to the sustainable development of the oil industry. Over the past several decades, continuous innovation and optimization in exploration techniques have significantly enhanced the accuracy of oil exploration and the scientific rigor of reservoir assessments. This paper examines the current technological landscape and research findings, delving into advancements in geophysical methods, well logging, and drilling. It particularly emphasizes the emerging quantitative analysis methods and the application of artificial intelligence. By integrating these technologies, we propose effective strategies to improve the precision of petroleum exploration and reservoir evaluation, thereby providing theoretical support for future technological advancements.

Keywords

Petroleum geological exploration; reservoir evaluation; geophysical technology; digitization; artificial intelligence.

1. Introduction

As global energy demand continues to rise, the development of petroleum resources faces unprecedented challenges. The scientific rigor and precision of petroleum exploration and reservoir evaluation are critical not only for the rational exploitation of resources but also for the sustainable supply of energy. In this context, technological innovation has emerged as a vital driving force behind advancements in oil exploration and production. In recent years, the continuous progress of science and technology has led to the emergence of numerous innovative techniques and methods, offering new possibilities for enhancing exploration efficiency and the accuracy of reservoir evaluations. This study aims to review the current technological landscape of petroleum geological exploration and reservoir evaluation, exploring the advantages and challenges of these emerging technologies in practical applications, thereby providing insights for future research and practice.

2. Current Status and Challenges of Petroleum Geological Exploration

In the context of rising global energy demand, petroleum geological exploration remains a crucial method for acquiring oil resources. However, it faces an ever-changing market environment and various technical challenges. Recent advancements in exploration technologies have created new opportunities for resource discovery and development. Nonetheless, these advancements are accompanied by pressures from environmental protection policies and the rise of renewable energy sources.

Understanding the current status of petroleum geological exploration and the primary challenges it faces is essential for the sustainable development of the industry. In the following

sections, we will delve into the existing landscape of petroleum geological exploration and the challenges that must be addressed to ensure its continued viability.

2.1. Current Status of Exploration

In recent decades, China's petroleum geological exploration has achieved significant milestones, particularly in the exploration and development of conventional oil and gas fields. However, as recoverable oil reserves gradually deplete, traditional exploration methods are increasingly inadequate to meet the growing energy demands. While seismic exploration and drilling technologies remain the mainstream approaches in China, their effectiveness is often limited when faced with complex geological environments. In regions with challenging geological conditions, such as faults, folds, and irregular reservoir distributions, the applicability and effectiveness of conventional exploration methods are severely tested. To adapt to this new landscape, exploration technologies urgently need to evolve toward more efficient and intelligent solutions to enhance resource discovery rates and development efficiency.

2.2. Major Challenges

2.2.1. Complex Geological Structures

Many potential oil and gas reservoirs in China are situated within intricate geological formations and reservoir structures, including deep and unconventional resources. These complex geological conditions impose higher demands on exploration technologies, as existing methods often struggle to accurately identify and assess the characteristics of these reservoirs. Consequently, there is an urgent need to develop more advanced geophysical exploration techniques and geological models to adapt to the evolving exploration environment.

2.2.2. Resource Depletion:

As proven oil reserves continue to decline, the development of lower-grade oil and gas resources is becoming increasingly important. These resources are often located at greater depths, making extraction more challenging and costly. Future exploration efforts will require more efficient and precise technological support to ensure sustainable oil and gas development under limited resource conditions.

2.2.3. Environmental and Economic Pressures

In the context of global climate change and heightened awareness of environmental protection, the impact of oil extraction on the environment is receiving increasing scrutiny. Traditional exploration and extraction techniques often come with high energy consumption and environmental pollution, placing significant pressure on the industry to reduce emissions and enhance energy efficiency. Additionally, fluctuations in the broader economic environment can lead to instability in oil prices, introducing uncertainty into exploration investments. This necessitates that technological innovations focus not only on economic benefits but also on environmental protection, thereby achieving sustainable development goals.

3. Application of Technological Innovation in Petroleum Exploration

Technological innovation plays a crucial role in petroleum exploration, driving sustainable development and efficiency improvements within the industry. As technology continues to advance, the application of various new techniques has significantly transformed traditional exploration methods, making resource discovery and development more precise and efficient. This section will focus on the application of geophysical technologies in petroleum exploration and the revolutionary changes they bring.

3.1. Geophysical Technology

In recent decades, China's petroleum geological exploration has achieved significant milestones, particularly in the exploration and development of conventional oil and gas fields. However, as recoverable oil reserves gradually deplete, traditional exploration methods are increasingly inadequate to meet the growing energy demands. While seismic exploration and drilling technologies remain the mainstream approaches in China, their effectiveness is often limited when faced with complex geological environments. In regions with challenging geological conditions, such as faults, folds, and irregular reservoir distributions, the applicability and effectiveness of conventional exploration methods are severely tested. To adapt to this new landscape, exploration technologies urgently need to evolve toward more efficient and intelligent solutions to enhance resource discovery rates and development efficiency.

3.2. Well Logging Technology

Advancements in modern well logging technology have provided strong support for petroleum exploration. Today, a wide variety of logging tools are available, enabling real-time acquisition of various physical and chemical data from downhole, including porosity, permeability, and fluid properties. The application of nuclear magnetic resonance (NMR) technology has particularly enhanced reservoir evaluation, allowing for in-depth analysis of fluid distribution and movement characteristics.

Furthermore, the introduction of advanced techniques such as multi-frequency laser measurements has significantly improved the accuracy and reliability of logging data. These technologies, especially when supported by smart wellhead technology, have optimized data collection and analysis during the logging process, making real-time monitoring and decision-making more scientific. Through in-depth analysis of logging data, better guidance can be provided for subsequent drilling and extraction strategies, thereby enhancing resource utilization efficiency.

3.3. Drilling Technology

Innovation in drilling technology is key to improving the efficiency of petroleum exploration and extraction. The widespread application of intelligent drilling and hydraulic fracturing technologies has significantly reduced resource consumption and costs during the drilling process. Intelligent drilling technology, through real-time monitoring and automated control, can adjust drilling parameters based on changes in geological conditions, thereby enhancing safety and efficiency. The application of underbalanced drilling and directional drilling techniques has also markedly improved exploration and extraction precision in complex geological environments.

These technologies not only reduce risks during drilling but also optimize resource extraction strategies, maximizing oil and gas recovery rates. By combining advanced drilling techniques with modern exploration methods, the petroleum industry is moving towards a more efficient and environmentally friendly future.

4. Research on Reservoir Evaluation Methods

Reservoir evaluation is a critical component of petroleum exploration and development, with its accuracy directly impacting the rational utilization of resources and development efficiency. In modern petroleum engineering, reservoir evaluation methods are continually evolving, encompassing traditional empirical approaches to contemporary quantitative analysis techniques. The introduction of integrated quantitative evaluation methods has made reservoir assessments more scientific and systematic. By integrating multiple data sources and analytical techniques, comprehensive quantitative evaluations can more accurately reflect reservoir characteristics, providing a reliable basis for decision-making.

4.1. Comprehensive Quantitative Evaluation

Comprehensive quantitative evaluation methods rely on extensive geological data, combining physical property analysis and regional analysis techniques. Through data fusion and weighting analysis, these methods enable more accurate classification and evaluation of reservoirs. With the development of data integration technologies, the efficiency and accuracy of reservoir evaluations have significantly improved, allowing for a more nuanced understanding of reservoir characteristics.

4.2. Mathematical Modeling and Simulation

Three-dimensional geological modeling and reservoir numerical simulation have become key technologies in reservoir evaluation. By constructing detailed three-dimensional models, dynamic simulations and fluid predictions can be performed on reservoirs. The application of numerical simulation techniques such as the finite element method (FEM) and finite difference method (FDM) has effectively enhanced the precision of reservoir evaluations. These methods allow for the analysis of fluid flow and reservoir behavior under various conditions, providing critical insights for development planning.

4.3. Application of Emerging Methods

In recent years, artificial intelligence and big data technologies have gradually found applications in petroleum geological exploration and reservoir evaluation. Techniques such as deep learning and machine learning algorithms can automatically identify complex geological structures and extract valuable information from vast datasets. This significantly enhances the automation and accuracy of reservoir evaluations, enabling geoscientists to make more informed decisions based on comprehensive data analysis. The integration of these emerging technologies represents a transformative shift in how reservoirs are assessed, paving the way for more efficient and effective resource management.

5. Development Trends and Outlook

As global energy demand continues to rise and environmental awareness increases, petroleum geological exploration and reservoir evaluation are undergoing profound transformations. Future development trends will primarily focus on three key areas: digitalization, intelligence, and sustainability, in order to address increasingly complex exploration challenges and the requirements for sustainable development.

5.1. Multidimensional Integrated Exploration

Multidimensional integrated exploration is set to become a significant direction for future petroleum exploration. By integrating various types of geophysical data, including seismic, gravity, and magnetic exploration techniques, a comprehensive analysis of subsurface resources can be achieved. This integrated approach not only enhances exploration accuracy but also effectively reduces exploration costs. For instance, combining seismic data with gravity data can lead to more precise identification of potential oil and gas reservoirs, thereby minimizing the risks associated with blind drilling. As data processing technologies advance, multidimensional integrated exploration will become even more efficient, propelling the entire industry toward a higher scientific level.

5.2. Digitalization and Intelligence

The application of digitalization and intelligent technologies will fundamentally transform traditional petroleum exploration models. Through big data analysis and artificial intelligence (AI), the in-depth mining of exploration data and real-time monitoring will become feasible. AI algorithms can automatically process and analyze vast amounts of data, identifying potential

exploration targets and enhancing the scientific accuracy of decision-making. Furthermore, the establishment of digital platforms will facilitate smoother information sharing and collaboration among different teams and departments, further improving work efficiency and responsiveness. In the future, digitalization and intelligence will extend beyond data analysis to encompass the optimization and automation of the entire exploration and development process.

5.3. Green and Environmental Technologies

With the global emphasis on sustainable development and environmental protection, the application of green and environmental technologies in petroleum exploration and extraction will become increasingly important. Developing low-carbon and environmentally friendly exploration and extraction technologies will not only mitigate the oil industry's environmental impact but also enhance resource utilization efficiency. For example, adopting more eco-friendly hydraulic fracturing techniques and wastewater treatment methods can reduce water resource consumption and pollution. Additionally, utilizing renewable energy and energy-saving technologies will help lower carbon emissions during exploration and production processes, achieving the goal of sustainable and green extraction.

6. Conclusion

With the ongoing development of petroleum geological exploration technologies and the integration of innovative reservoir evaluation methods, the efficiency of oil resource development continues to improve. The application of digitalization and intelligent technologies has provided new impetus for exploration and development efforts. Looking ahead, as exploration technologies continue to innovate and reservoir evaluation methods are refined, the petroleum industry will take more substantial steps toward sustainable development. This evolution not only enhances operational efficiency but also aligns with global environmental goals, ensuring that the industry can meet future energy demands responsibly and effectively.

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