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Single-Well Benefit Classification in Oil and Gas Reservoirs: Current Insights and Future Prospects

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Abstract **Original Research Article**

Against the backdrop of continuously growing global energy demand and increasingly tight oil and gas resources, single-well economic benefit evaluation has become a crucial tool for optimizing resource allocation and enhancing development efficiency. This paper reviews recent research progress in single-well benefit evaluation within oil and gas fields, covering benefit evaluation metrics, benefit classification standards, benefit-based production allocation, and single-well economic thresholds. It analyzes the achievements and shortcomings of existing research and outlines future research directions.

Keywords: oil and gas fields; single-well benefit evaluation; benefit evaluation metrics; benefit classification standards; benefit-based production allocation; single-well economic threshold.

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1. INTRODUCTION

As oil and gas field development progresses, resource quality gradually declines, and extraction costs persistently rise. Consequently, single-well economic benefit evaluation has become a critical link for oil and gas enterprises to optimize production decisions and enhance economic returns. Through scientifically sound single-well benefit evaluation, high-efficiency and low-efficiency wells can be accurately identified, providing a robust basis for resource allocation, production adjustments, and technical modifications. This paper will review recent research progress in single-well benefit evaluation within oil and gas fields, focusing on benefit evaluation metrics, classification standards, benefit-based production allocation, and single-well economic thresholds.

2. CURRENT STATUS OF RESEARCH

2. 1 Current Status of International Single-Well Benefit Research

The international oil and gas industry has an earlier start in the field of single-well benefit evaluation. After years of development, it has yielded substantial research outcomes. International scholars have conducted in-depth research on single-well benefit evaluation from multiple dimensions, covering key areas such as evaluation criteria, economic thresholds, and benefit-based production allocation.

Regarding evaluation criteria, international research emphasizes a comprehensive consideration of technical, economic, environmental, and other factors. For instance, Tao L. et al. (2016) incorporated metrics such as single-well production efficiency, energy consumption, and carbon emissions into the evaluation system to holistically assess overall well performance.[44] In economic threshold research, international scholars extensively utilize advanced mathematical models and algorithms, integrating regional fiscal policies and market environments to construct more precise economic threshold models. For example, Hu Y. et al. (2023) employed Monte Carlo simulation methods, accounting for the impact of various uncertainty factors on economic thresholds, thereby enhancing model reliability and practicality.[5] In benefit-based production allocation, international research emphasizes multi-objective optimization and dynamic adjustments. By establishing complex optimization models that comprehensively consider multiple objectives such as production volume, cost, profit, and recovery factor, single-well benefit maximization is pursued. Simultaneously, production allocation schemes are adjusted in real-time based on market fluctuations and development progress, improving operational flexibility and adaptability.

2. 2 Current Status of Domestic Single-Well Benefit Research

Domestic scholars, building upon international experience and considering the specific realities of China's oil and gas fields, have conducted extensive targeted research. Regarding single-well benefit classification standards, several distinctive methodologies have been proposed. For example, Yang Huixian et al. (2007) employed a "revenue vs. cost indicator classification method," preliminarily classifying well benefits by comparing metrics like revenue-to-cost ratio and profit-to-cost ratio. [0] Wang Weihua et al.'s (2009) "single-well accounting classification method" categorizes wells into different benefit grades based on detailed single-well cost accounting. [38] Zhang Jijun and Wang Shuyuan's (2010) "cost range classification method" sets classification standards based on the cost range of individual wells.[37] However, these methods exhibit a degree of subjectivity in indicator selection and weight assignment, leading to poor comparability between different research results.

In single-well economic threshold research, domestic studies often employ traditional methods like the breakeven analysis and discounted cash flow (DCF) methods to calculate thresholds such as initial production limits and economic recoverable reserves limits. For instance, Meng Xianjun et al. (2001) utilized breakeven principles and production decline laws to establish models for production limits, investment limits, price limits, cost limits, and other economic limit indicators for different types of oil wells.[4] However, these models rely, to some extent, on simplifying assumptions, such as the clear distinction between fixed and variable costs, which can deviate from the complexities of actual development. Regarding benefit-based production allocation research, Liu Bin et al. (2011) proposed a method establishing an optimization model based on single-well benefit evaluation data, sorted through a unified platform, targeting maximum benefit, minimum cost, and breakeven. [36] While achieving benefit-based allocation for oilfield companies, the goal setting might be overly simplistic, focusing primarily on either cost or benefit while neglecting the comprehensive consideration of other important indicators like production volume and recovery factor. Furthermore, development characteristics and economic viability differ significantly across various reservoir types; existing models may lack sufficient flexibility to accommodate these differences.

3. RESEARCH CONCLUSIONS AND PROSPECTS

3.1 Research Conclusions

Despite existing shortcomings, current research has achieved many commendable results. In indicator system construction, scholars both domestically and internationally have identified a series of key factors influencing single-well benefits—such as production volume, cost, price, and geological conditions—and have attempted to integrate these factors into evaluation systems, providing a foundation for comprehensive assessment. For example, Zhang Jiwei (2016) clarified single-well cost attribution and accounting methods by establishing an easily controllable economic benefit evaluation model for single wells in production plants/mines, offering an important reference. [26] In economic threshold model research, Yuan Li et al. (2017) calculated initial oil production limits and economic recoverable reserves limits for single wells under different well depths and prices for various reservoir types, developing economic threshold charts under different oil prices to provide an economic basis for single-well investment decisions.[23] Regarding benefit-based production allocation methods, Luo Yuhan et al. (2018) further optimized existing allocation methods by introducing multi-objective optimization concepts, making allocation schemes more scientific and rational, thereby helping to improve single-well development efficiency.[19]

3.2 Existing Problems

Current research still faces several pressing challenges. The single-well benefit classification indicator system lacks unified standards. Different studies employ diverse indicator systems and evaluation methods, making evaluation results difficult to compare and apply directly. Economic threshold models inadequately account for the complexity and uncertainty inherent in actual development processes, such as geological risks and market volatility, leading to deviations between model predictions and real-world outcomes. Existing benefit-based production allocation methods exhibit deficiencies in goal setting and model adaptability, struggling to meet the development needs of different gas reservoir types and lacking comprehensive consideration of multiple objectives.

3.3 Future Research Directions

To overcome current research limitations, future efforts can seek breakthroughs in the following areas:

Indicator System Construction: Strengthen interdisciplinary collaboration, integrating knowledge from geology, engineering, economics, etc., to build more systematic and scientific single-well benefit classification indicator systems. Employ objective weighting methods (e.g., entropy weight method, principal component analysis) to reduce subjectivity in assigning indicator weights.

Economic Threshold Model Optimization: Introduce dynamic adjustment mechanisms to account for the influence of geological risks, market fluctuations, and other factors on economic thresholds, enhancing model adaptability and accuracy. For example, drawing on methods like those used by Dong Shangfu et al. (2022) for shallow marine geological conditions, using DCF to calculate economic thresholds for different development scenarios and creating scenario selection charts. [12]

Benefit-Based Production Allocation Method Improvement: Establish multi-objective optimization models for production allocation, comprehensively considering cost, benefit, production volume, recovery factor, and other objectives. Develop differentiated allocation strategies to improve

practicality and flexibility.

Machine learning (ML), as a powerful data analysis tool, holds significant potential for application in single-well benefit classification research. By learning from and analyzing vast amounts of historical data, ML algorithms can automatically uncover underlying patterns and relationships, providing more accurate predictions for single-well benefit evaluation. For instance, decision tree algorithms can classify and predict well benefits based on geological parameters and production data; support vector machine (SVM) algorithms can build predictive models for future well benefits. Applying these methods can significantly enhance the accuracy and efficiency of single-well benefit evaluation.

Big data analytics technology enables the real-time collection, storage, and analysis of massive single-well datasets, providing comprehensive data support for benefit classification research. Comparative analysis of data from wells in different regions and reservoir types can reveal common factors and unique differences influencing well benefits, informing targeted development strategies. Simultaneously, big data analytics facilitates real-time monitoring and early warning of well production processes, enabling the timely identification of potential issues and risks to ensure safe and efficient production. For example, analyzing historical production data can predict future production trends, offering a scientific basis for production decisions.

Digital twin technology, by creating virtual models of single wells, enables real-time simulation and optimization of the production process. Within the virtual model, different development scenarios can be simulated and tested to assess their impact on well benefits, thereby selecting the optimal development plan. Additionally, digital twin technology allows for remote monitoring and predictive maintenance of well equipment, identifying potential failures in advance, reducing downtime, and improving production efficiency. For instance, the digital twin model can simulate well production under different extraction pressures to optimize operational parameters and enhance recovery factor and economic returns.

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