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Research Methods and Prospects of Oil and Gas Reservoir Numerical Simulation

Nayan He, Haifeng Yuan, Gaocheng Li, Jingnan Chen

School of Petroleum Engineering, Xi'an Shiyou University, Xi'an 710065, China

Abstract: This paper briefly describes the development process of oil and gas reservoir numerical simulation, introduces the method and application of oil and gas reservoir numerical simulation, and predicts the future development trend of oil and gas reservoir numerical simulation on this basis, To help extract oil better and more efficiently.

Keywords: Hydrocarbon Reservoir Numerical Simulation; Numerical Simulation Method; Numerical Simulation Application.

1. Introduction

An oil and gas reservoir are a geological formation in which a large amount of oil and gas resources are stored underground, which is essential for effective oil and gas extraction and storage. As an important tool to study and predict oil and gas exploitation behavior, the numerical simulation of oil and gas reservoirs has been widely used and developed in the past decades. In this paper, the development history, methods and applications of oil and gas reservoir numerical simulation will be reviewed, and the future development trend will be prospected.

2. Development History of Oil and Gas Reservoir Numerical Simulation

The development of oil and gas reservoir numerical simulation can be traced back to the 1960s, when the reservoir description and reservoir evaluation were mainly based on empirical formulas and models. With the advancement of computer technology, numerical simulation methods have been gradually applied. In the 1970s, the finite difference method was introduced into the numerical simulation of oil and gas reservoirs, which provided more accurate simulation results. In the 1980s, numerical methods such as finite element method and boundary element method were applied to the numerical simulation of oil and gas reservoirs, which further improved the simulation accuracy. Since the 1990s, with the advent of parallel computing and high-performance computers, the computational power of numerical simulation has been greatly improved, which provides the possibility for more complex oil-gas reservoir simulation.

3. Hydrocarbon Reservoir Numerical Simulation Methods

3.1. Reservoir Modeling

Reservoir modeling is the first step of numerical simulation. Through modeling the geometry and physical properties of the reservoir, it provides the basis for the subsequent numerical calculation. The reservoir modeling methods mainly include two kinds of methods: deterministic modeling and stochastic modeling. The deterministic modeling includes five methods: reservoir sedimentology method, Krieger method, reservoir seismology method, horizontal well modeling method and outcrop prototype modeling method [1]. Stochastic modeling methods include sequential Gaussian simulation method, sequential indication simulation method, truncated Gaussian simulation method and other three methods [2].

3.2. Description of Physical Process

The numerical simulation of oil and gas reservoirs requires the description of various physical processes, including multiphase flow [3], mass transfer [4], etc. The numerical simulation method can establish mathematical models based on conservation equation, Darcy law and other basic principles, and calculate the flow field, pressure field and temperature field by numerical discretization and solution methods.

3.3. Numerical Discretization and Solution

Numerical simulation methods discretize continuous physical processes into algebraic equations on a discrete grid, and then compute numerical solutions to the equations through iterative solving methods. Commonly used numerical methods include finite difference method, finite element method, boundary element method and finite volume method.

3.4. Parameter Estimation and Model Verification

It is necessary to estimate and adjust some parameters, such as permeability, porosity, fluid properties, etc., in order to make the simulation results closer to the actual situation. Parameter estimation methods include historical data matching, inversion methods and data assimilation, etc. By comparing and verifying with actual production data, the accuracy and credibility of simulation results are improved.

3.5. Uncertainty Analysis

There are certain uncertainties in geological and fluid parameters of oil and gas reservoirs, and uncertainty analysis is an important means to evaluate the reliability and certainty of simulation results. Uncertainty analysis methods include sensitivity analysis, statistical analysis and Monte Carlo simulation, etc., which can evaluate the influence of different parameters on the simulation results and provide information such as probability distribution and confidence interval.

4. Application of Numerical Simulation of Oil and Gas Reservoirs

4.1. Optimization of Reservoir Development Strategy

Oil and gas reservoir numerical simulation can simulate oil and gas production and recovery efficiency under different development strategies, and provide decision-making basis for reservoir development. By simulating the effects of different development schemes, the water injection scheme can be optimized, the development method improved, and the oil and gas recovery efficiency and economic benefits can be increased.

4.2. Prediction of Reservoir Behavior

Oil and gas reservoir numerical simulation can predict the dynamic behavior of oil and gas reservoirs, such as production changes, pressure distribution and water drive effect. Through simulation and prediction, the potential and exploitation prospect of oil and gas reservoirs can be evaluated, and the resource evaluation and investment decision can be guided.

4.3. Reservoir Management and Optimization

Reservoir numerical simulation can assist field managers in reservoir management and optimization. By simulating and analyzing the production situation and dynamic changes of oil and gas reservoirs, reasonable production control strategies can be formulated to delay the occurrence of adverse phenomena such as water channeling and gas deposition, and extend the production life of oil and gas fields.

4.4. Prediction of Environmental Impact

Oil and gas reservoir numerical simulation can be used to predict the environmental impacts of oil and gas extraction. Through simulation analysis, the potential impacts of exploitation activities on groundwater resources, surface geomorphology and ecological environment can be assessed, providing scientific basis for environmental protection and sustainable development.

5. Development Trend of Oil and Gas Reservoir Numerical Simulation

The development trend of oil and gas reservoir numerical simulation in the future mainly includes the following aspects:

5.1. Multi-physical Coupling Simulation

With the deepening understanding of reservoir development and production processes, more and more physical processes have been recognized as interacting with each other. The future oil and gas reservoir numerical simulation will pay more attention to the multi-physical coupling simulation, including the coupling simulation of multiple physical processes such as fluid flow, rock deformation, chemical reaction and heat conduction, so as to describe the behavior of oil and gas reservoirs more accurately.

5.2. High-resolution Simulation

Traditional oil and gas reservoir numerical simulations often use coarse grids to reduce the amount of computation, but this can overlook some details and small-scale effects. The future development trend will pay more attention to high-resolution simulation, through finer meshing and more accurate description of physical properties, to simulate more detailed underground reservoir structure and flow behavior, such as the flow law of materials at the micron and nano scale.

5.3. Data-driven Simulation

With the rapid development of big data and machine learning technology, the application of data-driven simulation in the numerical simulation of oil and gas reservoirs will increase. By combining a large amount of actual production data and geological data, using machine learning algorithms and data mining methods, parameters can be estimated more accurately, models can be optimized, and the behavior of oil and gas reservoirs can be predicted.

5.4. Intelligent Optimization Algorithm

Traditional numerical simulation often needs to optimize the model and parameters through trial and error, which is huge and time-consuming. The future development trend will pay more attention to the application of intelligent optimization algorithms, such as genetic algorithm, particle swarm optimization algorithm and deep reinforcement learning, to find optimal solutions quickly and effectively and improve the efficiency and accuracy of numerical simulation.

5.5. Visualization and Interactivity

The result of a reservoir numerical simulation is often a large data set, and it is a challenge for decision makers and researchers to intuitively understand and analyze the simulation results. The future development trend will focus more on visualization technology and interactivity, providing more intuitive and intuitive tools for displaying and analyzing simulation results through means such as 3D visualization, virtual reality and data interaction.

6. Summary

Oil and gas reservoir numerical simulation, as an important tool to study and predict oil and gas exploitation behavior, has made remarkable development and application in the past decades. Through reservoir modeling, physical process description, numerical discretization and solution methods, reservoir numerical simulation can optimize reservoir development strategies, predict reservoir behavior, manage oil and gas fields, and assess environmental impacts. Future trends will focus more on multi-physics coupled simulation, high-resolution simulation, data-driven simulation, intelligent optimization algorithms, and visualization and interactivity. These trends will improve the accuracy, efficiency and visual presentation of simulation results, providing a more reliable scientific basis for oil and gas extraction and management decisions.

Although the numerical simulation of oil and gas reservoirs has made remarkable progress, there are still some challenges and issues that need to be addressed. Firstly, there are uncertainties in geological and fluid parameters of hydrocarbon reservoirs, and parameter estimation and uncertainty analysis are still key research areas. Secondly, the increase of simulation scale and computational complexity requires higher computational resources and algorithms, so it is necessary to further improve the computational efficiency and develop more suitable algorithms for the numerical simulation of oil and gas reservoirs. In addition, the acquisition, processing and application of data is also a challenge, and how to integrate data of different types and sources to improve the quality and availability of data will be one of the future research directions.

To sum up, numerical simulation of oil and gas reservoirs plays an important role in oil and gas exploitation and management, and is of great significance for the efficient development and sustainable utilization of oil and gas resources. With the continuous advancement of technology and the increase of application demand, the numerical simulation of oil and gas reservoirs will continue to develop and contribute to the sustainable development of the oil and gas industry by combining with the research in other related fields.

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