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The Current Situation and Development Trend of Shale Oil Exploitation Technology at Home and Abroad

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Abstract

This paper analyzes the global shale oil resource pattern, exploitation status and technological development. The total amount of global shale oil recoverable resources reaches 700-80 billion tons, mainly distributed in North America, China and Russia, with the United States leading production in 2023 accounting for more than 65% of the world's production in 2023, and China being the third largest resource country, with a record high in 2023. China focuses on the technological innovation of continental shale oil, and has made breakthroughs in the three national demonstration zones to form characteristic technologies such as carbon dioxide pre-fracturing. Internationally, the United States is leading in the fields of three-dimensional development and intelligent equipment, Europe focuses on environmental protection technology, and Russia is tackling ultra-deep development. There are differences between China and the United States in geology, concepts, technology, etc., and the current shale oil development is facing challenges such as low oil recovery and environmental constraints, and the future technology will develop towards low-carbon, intelligent and cost-effective. China needs to take the path of differentiated innovation and promote the transformation of industries to benefit development to achieve the national energy security goal.

Keywords

Shale Oil Extraction Technology; Shale Oil Extraction Technology; Development Trend; Comparison of Chinese and American Technologies; Continental Shale Oil Development.

1. Introduction

In the context of the global energy structure transformation, shale oil, as a key component of unconventional oil and gas resources, has become increasingly prominent. According to the latest exploration data, shale oil resources have been discovered in 75 basins in 21 countries, with a total recoverable resource of 700-80 billion tons, mainly distributed in North America, China and Russia. The United States has long occupied a dominant position in global shale oil production by virtue of its advantages in marine shale oil resources and technological first-mover advantages. Bai Guoping [1] wait, According to EIA publicly available data. As of the end of 2018, the total technically recoverable resources of shale oil in the United States were 205×108t, of which the cumulative proven recoverable reserves are 49.7×10^8t (cumulative oil production 17.9×10^8t + the remaining is proven 31.8×10^8t), with a proven rate of 24.2%. In 2022, the United States shale oil production was 3.9×10^8t, accounting for 65.6% of U.S. crude oil production. In 2023, it will produce 414 million tons (more than 65% of the world's total production), making it the world's largest shale oil producer. our country is rich in shale oil resources, which is an important successor area to promote domestic crude oil production and stabilization [2,8]. As the third largest shale oil resource, China has recoverable reserves of 32 billion barrels (about 4.3 billion tons), mainly distributed in five major sedimentary basins including Ordos, Songliao, Junggar, Sichuan and Bohai Bay, and the production in 2023 will exceed 4 million tons, a record high. It has the characteristics of good continuity, high pressure

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coefficient and strong liquidity of crude oil; In China, continental shale is the main characteristic, which generally has strong reservoir heterogeneity, burial depth (mostly more than 3000 meters), high viscosity of crude oil, and low pressure coefficient. The United States mainly adopts the multi-layer three-dimensional development model of long horizontal wells, while China needs to develop a more targeted continental shale oil development technology system. Breakthroughs have been made in the field of shale oil development, and a number of national-level demonstration zones have been established, forming a series of distinctive development technologies. Internationally, the United States, Europe, Russia, etc. are also constantly innovating in their respective technical fields.

However, shale oil development still faces many technical challenges such as low oil recovery, environmental constraints, and insufficient economic benefits. Therefore, an in-depth analysis of the current situation, differences and development trends of shale oil exploitation technology at home and abroad is of great significance to promote the sustainable development of the shale oil industry and ensure national energy security. This paper aims to systematically sort out the global shale oil resource pattern and exploitation status, analyze the development trends of advanced technology in China and the world, compare the technological differences between China and the United States, discuss the current challenges and future trends, and provide reference for the further development of shale oil development.

2. China's Shale Oil Development Progress and Technological Breakthroughs

Although China's shale oil exploration and development started late, breakthroughs have been made through continuous technical research, and the Jimsar National Continental Shale Oil Demonstration Zone, Gulong Continental Shale Oil National Demonstration Zone, and Shengli Jiyang Continental Shale Oil National Demonstration Zone have been established [9].

2.1. Xinjiang Jimsar Demonstration Zone

Located in the eastern part of the Junggar Basin, the first million-ton continental shale oil demonstration zone will be built in 2024, with a daily output of more than 4,000 tons. The block adopts a full life cycle management model, reducing the investment in a single well by more than 40%, and the fracturing efficiency reaches 4.9 levels/day (an increase of 9% year-on-year), laying the foundation for achieving the annual production target of 1.7 million tons by 2025.

2.2. Daqing Gulong Demonstration Zone

Focusing on the development of cretaceous shale oil, through the "dense cutting + small well spacing" three-dimensional well layout mode, single well EUR (estimated final recoverable reserves) exceeded 40,000 tons.

2.3. Shengli Jiyang Demonstration Zone

Table 1. Development Progress of Major Shale Oil Demonstration Zones in China (2024)

Demonstration area	Annual output	Annual output	EUR level
Xinjiang Jimsar	1 million tons	Full lifecycle management and CO_2 pre-fracturing	40-60 thousand tons
Daqing Gulong	Steadily growing	Dense cutting three-dimensional fabric wells	less than 40,000 tons
Shengli Jiyang	1900 tons/day	Full-cycle production regulation	44,000 tons

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Shengli Jiyang Demonstration Zone: Oil production will be 296,000 tons in 2023, and daily production will jump to 1,900 tons in 2024.

In terms of core technological innovation, China has formed a series of characteristic technologies:

Carbon dioxide pre-fracturing technology: The application effect is remarkable in Jimsar, Changqing and other blocks, improving the fluidity of crude oil through the supercritical state of carbon dioxide, increasing the cumulative oil production per kilometer of shale section in the high-viscosity area by 27%, and extending the self-injection period by more than 300 days.

Three-dimensional development technology of dense cutting: The design of 100-150 meters radial half-fracture length is adopted to form a superimposed well layout mode with horizontal well sections as the axis, which greatly improves the oil recovery in Changqing Oilfield tests.

Waterless fracturing technology: Jilin Oilfield has successfully implemented 1,000 cubic meters of carbon dioxide dry sand fracturing, saving 10,000 cubic meters of water in a single well, and realizing clean mining without aqueous phase, no residue, and fast backflow.

Through fracturing technology: The success rate of through-layer fracturing of Changqing Oilfield's Hua H100 platform reaches 85.7%, which effectively communicates the bedding joints in the thin interlayer and improves the height of the vertical fractures.

3. International Advanced Technology Development Trends

The core breakthroughs of shale oil development in the United States are reflected in three major areas:

Three-dimensional development technology iteration: from single-layer volumetric fracturing to multi-layer three-dimensional fracturing, the cluster spacing is reduced to less than 10 meters, the sand addition strength reaches 5 tons/meter, and the output per unit length of the horizontal section is increased by more than 30%. For example, in the Permian Basin, the cost of oil per barrel was reduced from US$80 to US$29 using the model of ultra-long horizontal section (> 3000 m) and superwell plant (16 wells on a single platform).

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The most widely used. Through the model of "intermediate well throughput and simultaneous coarse/blowout oil recovery of both wells", the daily output of the well group in the Guandong area has been increased from 10.8 tons to 23.6 tons, and the validity period is more than 450 days.

Table 2. Comparison of technical parameters of shale oil development between China and the US

Technical parameters	US	China
Horizontal segment length	2500-3800 meters	1500-2500 meters
The number of floors used in three dimensions	3-5 layers	1-3 layers
Fracturing efficiency	6-8 segments/day	1-2 segments/day
Bridge plug drilling speed	4 minutes/piece	15-30 minutes/piece
Quartz sand application ratio	more than 98%	87%

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European countries focus on environmental protection technology innovation, such as Schlumberger's ReWind freshwater-free fracturing liquid system and Halliburton's EcoShield fracturing backflow fluid circulation technology, achieving a 95% water reuse rate. Russia focuses on the development of ultra-deep shale oil (> 4,000 meters) and relies on high-frequency vibration fracturing technology to reduce the rupture pressure

4. Comparative Analysis of Shale Oil Development Technology in China and the United States

There are systemic differences in shale oil development between China and the United States, which are mainly reflected in five dimensions:

Differences in geological conditions: The United States is dominated by marine shale, with continuous and stable reservoirs, large single layer thickness (20-50 meters), and high crude oil API degree. China is dominated by continental shale, which has strong heterogeneity, thin single oil layer (such as only 1.5 meters in Jimsar), and high viscosity of crude oil.

Differences in development concepts: The United States has established a full life cycle energy maintenance concept, fine pressure control production (0.01Mpa/d accuracy); China is still in the production-oriented stage, and the formation energy conservation technology system is not yet perfect.

Engineering technology gap: Drilling efficiency: The ultra-long horizontal section (>3000 meters) in the United States has become the norm, and the average level in China is about 2000 meters, Fracturing age: The fracturing efficiency of the US platform is 6-8 segments/day, while in China, it is only 1-2 segments/day, Tool performance: The drilling speed of bridge plugs in the United States is 4 minutes/piece, and it takes 15-30 minutes in China.

Materials and equipment: Fracturing liquid system: The proportion of clean water-based slippery water in the United States exceeds 90%, and China's high-viscosity slippery water (30-50 mPa·s) is still dominant, Propp application: 98% of quartz sand in the United States, 87% in China (only 47% at depths above 3,500 meters).

Data intelligence: The United States has built FracFocus databases to share fracturing data of 100,000 wells, and the data systems of China's oilfields are isolated and not uniform.

5. Technical Challenges and Development Trends

5.1. Current Technical Bottlenecks

Low oil recovery: The average global shale oil recovery rate is less than 10%, mainly due to the lack of utilization of micro-nano hole pipes (accounting for more than 70%) and limited fracture network control.

Environmental constraints: hydraulic fracturing consumes 1.5-20,000 cubic meters of water in a single well, and it is difficult to treat the backflow fluid; Large-scale development induces the risk of geological collapse (such as the Sichuan Basin).

Problems in the prevention and control of casing deformation: The casing rate of hydraulic fracturing in Jiyang shale reaches 8 / 100 sections, and it is necessary to optimize the control of stress interference.

Economic bottleneck: The cost of shale oil extraction in China is 40% higher than that of the United States, making it difficult to make a profit when oil prices are below $60 per barrel.

5.2. Cutting-Edge Technology Development Trends

In the future, shale oil technology will develop in three directions: low-carbon, intelligent and efficient:

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Nano-enabled CO_2 technology: through the integration of supercritical CO_2 fracturing-displacement-displacement, it not only improves oil recovery but also realizes carbon sequestration, Laboratory studies have shown that carbon dioxide has a 40% higher adsorption capacity in shale than methane, which can effectively replace adsorbed oil and gas.

Intelligent closed-loop fracturing system: based on real-time microseismic monitoring and AI dynamically optimized crack propagation, As developed by Harry Burton FracNet system achieves a 91% degree of seam matching.

In-situ conversion technology: Sinopec has developed microwave heating technology to heat shale to more than 300°C through an underground microwave generator, so that kerogen can be directly cracked into light oil, which is expected to increase the oil recovery rate to more than 40%.

Expansion of waterless fracturing system: Develop waterless technologies such as liquid propane fracturing and supercritical carbon dioxide sand adding, and aim to increase the proportion of waterless fracturing in the Jimsar Pilot Zone to 30% by 2026.

6. Conclusion and Prospects

Global shale oil development has formed a dual-track pattern of "leading the sea phase and following up on land". The United States has consolidated its dominance through continuous technological innovation, with shale oil production expected to exceed 9 million barrels per day in 2024; Although China started late, it is expected to achieve the target of 10 million tons of production by 2025 by relying on the construction of the three demonstration zones and technical research.

Future technological breakthroughs need to focus on three dimensions:

Basic theoretical innovation: deepen the research on the seepage mechanism of micro and nano pore throats, and establish the theory of "artificial oil and gas reservoirs" for continental shale oil.

Engineering technology iteration: Develop three-dimensional development 2.0 technology (above 5 layers), intelligent fracturing equipment, and carbon dioxide full-cycle utilization technology chain.

Green and low-carbon transformation: Build an integrated technology system of "waterless fracturing, flowback fluid regeneration, and carbon sequestration", and aim to reduce carbon emissions from a single well by 30% by 2025.

China's shale oil development needs to take a differentiated innovation path: according to the characteristics of continental geology, the development of a technical system of "dense cutting three-dimensional well + carbon dioxide pre-fracturing + early energy replenishment", At the same time, we will accelerate the research and development of domestic equipment (such as the 7000 electric drive fracturing vehicle) and the construction of industry data platforms, and promote the transformation of the shale oil industry from "scale breakthrough" to "benefit development", Finally, the national energy security strategic goal of stable crude oil production of 200 million tons will be achieved.

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