ISSN: 2688-8645

Research Progress and Challenges of Shale Oil Reservoir Characteristics

Linxi Jia

School of Xi'an Shiyou University, Xi'an 510000, China

Abstract

This article systematically reviews the latest progress and main challenges in the research of shale oil reservoir characteristics. As an important unconventional oil and gas resource, the study of shale oil reservoir characteristics is of great significance for resource evaluation and development. The article elaborates in detail on the main characteristics of shale oil reservoirs from five aspects: geological features, physical properties, geochemical features, mechanical properties, and development characteristics. It analyzes the key issues and challenges in current research and looks forward to future research directions. The research shows that shale oil reservoirs have typical low porosity and low permeability characteristics, with well-developed nanoscale pores, strong reservoir heterogeneity, and are controlled by multiple geological factors. Future research should focus on multi-scale characterization techniques, digital core technology, and the application of artificial intelligence to promote the efficient development of shale oil.

Keywords

Shale Oil; Reservoir Characteristics; Unconventional Oil and Gas; Nano-pore; Reservoir Evaluation.

1. Introduction

With the depletion of conventional oil and gas resources, the development of unconventional oil and gas resources has become an important part of the global energy strategy. Shale oil, as one of the important unconventional oil and gas resources, has attracted wide attention in recent years. Shale oil refers to the oil resources occurring in organic-rich shale series, including adsorbed state and free state. Compared with conventional oil and gas reservoirs, shale oil reservoirs have typical characteristics of low porosity and low permeability, which is difficult to develop and requires high technical requirements.

The study of shale oil reservoir characteristics is the basis of resource evaluation and development, which is of great significance for formulating reasonable development plan. This paper aims to systematically review the latest progress in the study of shale oil reservoir characteristics, analyze the main challenges currently faced, and look forward to the future research direction, so as to provide theoretical reference for the efficient development of shale oil resources.

2. Geological Characteristics of Shale Oil Reservoir

The geological characteristics of shale oil reservoir mainly include sedimentary environment, lithology combination and structural characteristics. In terms of sedimentary environment, shale oil reservoirs are mostly formed in deep-water and semi-deep-water sedimentary environments, such as lake deep water area and continental shelf. These environments are characterized by low energy and hypoxia, which is conducive to the preservation and enrichment of organic matter. For example, the Bakken shale in North America was formed in

ISSN: 2688-8645

the inland sea basin of the Devonian-Mississippian period, while the 7 member shale of the Triassic Yanchang Formation in the Ordos Basin in China was deposited in a large freshwater lake environment.

In terms of lithology, shale oil reservoirs are usually interbedded with black shale, siltstone and thin sandstone. Organic-rich shale is the main source rock and reservoir, while thin sandstone or siltstone may provide better seepage channels. It is worth noting that micro-fracture systems are often developed in shale oil reservoirs, and these fractures can be formed either by primary sedimentary structures, or by late tectonic movement or diagenesis.

Structural characteristics have an important influence on the distribution and quality of shale oil reservoirs. Regional tectonic setting determines the type and evolutionary history of sedimentary basins, while local structures control the preservation conditions of shale reservoirs. For example, North American shale oil is mainly distributed in stable craton basins, while Chinese shale oil is mostly developed in specific layers of superimposed basins. Structures such as faults and folds not only affect the maturity of organic matter and the degree of fracture development of shale, but also may form channels or traps for shale oil transport.

3. Physical Characteristics of Shale Oil Reservoir

The most significant physical characteristics of shale oil reservoirs are their extremely low porosity and permeability. The porosity is usually less than 10% and the permeability is mostly in the Nadasi level, which makes the shale oil reservoir with typical tight characteristics. However, it is this tightness that allows shale oil to be preserved for long periods of time without large-scale migration.

In terms of pore structure, shale oil reservoirs develop multi-scale pore systems, including micron pores, nanoscale pores and micro-fractures. Among them, nanoscale pores (usually 2-50nm pores) are of great significance for the reservoir of shale oil. These nano-pores are mainly derived from organic pores formed by the thermal evolution of organic matter, clay mineral interlayer pores, brittle mineral intergranular pores and solution pores. The results show that organic pore is an important reservoir space for shale oil, and its development degree is closely related to the type and maturity of organic matter.

Reservoir heterogeneity is another important feature of shale oil reservoirs. This heterogeneity is manifested both vertically and horizontally. Vertically, shale oil reservoirs are usually composed of multiple thin layers, and the differences in lithology, physical properties and oil content of each layer are obvious. Laterally, influenced by sedimentary microfacies and diagenesis, reservoir properties will also change significantly. This strong heterogeneity poses great challenges for shale oil development.

4. Geochemical Characteristics of Shale Oil Reservoirs

Organic geochemical characteristics are the key indexes for evaluating shale oil reservoirs. Total organic carbon content (TOC) is an important parameter to measure the hydrocarbon generation potential of shale, and the TOC of high-quality shale oil reservoirs is usually greater than 2%. The type of organic matter mainly affects the nature and quantity of oil and gas, and type I and type II kerogen are more beneficial to oil generation. Maturity determines the degree of thermal evolution of organic matter, and the optimal maturity range (Ro) of shale oil reservoirs is usually between 0.7% and 1.3%.

Mineral composition has an important influence on the mechanical properties and fracturing effect of shale oil reservoirs. The minerals in shale oil reservoir mainly include quartz, feldspar, carbonate minerals and clay minerals. Among them, the reservoir with high content of brittle minerals such as quartz is more likely to form complex fracture network, which is conducive to

ISSN: 2688-8645

shale oil development. The high clay mineral content may lead to the plastic enhancement of the reservoir, which is not conducive to fracturing. In addition, mineral composition also affects the adsorption properties and fluid sensitivity of shale.

In terms of fluid properties, shale oil usually has a high density and viscosity, with API degrees mostly between 30 and 45°. Shale oil contains more polar components and heavy components, which is obviously different from conventional crude oil. These special properties of the fluid will affect its state of occurrence and flow behavior in the nanopores, and then affect the development effect.

5. Mechanical Characteristics of Shale Oil Reservoir

Rock mechanics characteristics are the basis of fracturing reconstruction of shale oil reservoirs. Shale oil reservoirs usually have high Young's modulus and low Poisson's ratio, showing strong brittleness characteristics. This brittle feature is conducive to the formation of complex fracture networks during hydraulic fracturing. However, the mechanical properties of different shale oil reservoirs are quite different, which are mainly controlled by mineral composition, organic matter content and diagenesis.

The state of ground stress has an important influence on shale oil development. The current ground stress field determines the propagation direction and morphology of fracturing fractures. In general, the direction of the maximum horizontal principal stress controls the extension direction of the crack, while the stress difference affects the complexity of the crack. The stress state and anisotropy of the reservoir should be considered in a reasonable fracturing design.

Fracture development characteristics are important evaluation indexes of shale oil reservoirs. Natural fractures can improve the permeability of the reservoir and provide flow channels for shale oil. According to the origin, the fractures in shale can be divided into tectonic fractures, diagenetic fractures and overpressure fractures. Fracture density, orientation, opening and filling degree will affect the development of shale oil. It is worth noting that the interaction between natural fractures and artificially fractured fractures is the key to shale oil production.

6. Development Characteristics of Shale Oil Reservoirs

The development characteristics of shale oil reservoir are mainly reflected in two aspects: production decline law and development technology. In terms of production decline, shale oil Wells usually have the characteristics of high initial production but rapid decline. This is due to the very low permeability of shale oil reservoirs leading to a rapid drop in pressure. The typical decline curve can be divided into three stages: the initial rapid decline stage, the middle slow decline stage and the late stable production stage. The study of decline law is of great significance for the prediction of production performance and the optimization of development scheme of shale oil Wells.

In terms of development technology, horizontal well drilling and hydraulic fracturing are two key technologies in shale oil development. Horizontal Wells can maximize reservoir contact areas, while large-scale hydraulic fracturing can create effective seepage channels in tight reservoirs. In recent years, new fracturing technologies such as volumetric fracturing, repeated fracturing and synchronous fracturing have emerged, greatly improving the efficiency of shale oil development. In addition, gas injection enhanced oil recovery technology, nanofluid technology and in situ conversion technology also show good application prospects.

The analysis of development dynamic characteristics is an important content of shale reservoir management. Through production data analysis, pressure monitoring, and microseismic monitoring, fracturing performance can be evaluated, productive areas identified, and

ISSN: 2688-8645

development plans optimized. It is worth noting that the interference phenomenon of "parent well" and "child well" often occurs in the process of shale oil development, which needs to be solved by reasonable well spacing design and production system optimization.

7. Major Issues and Challenges in Current Research

The study of shale oil reservoir characteristics still faces many challenges. In terms of characterization technology, how to accurately characterize nanoscale pore structure and fluid occurrence state is an urgent problem to be solved. Traditional experimental methods such as helium porosity measurement, high pressure mercury injection and gas adsorption can provide partial information, but it is difficult to fully reflect the complex pore system of shale oil reservoirs. Although emerging technologies such as nano-CT, FIB-SEM and atomic force microscopy provide new research methods, their application scope and accuracy still need to be improved.

In terms of evaluation methods, the existing reservoir evaluation parameters and standards are mainly for conventional oil and gas reservoirs, and are not fully applicable to shale oil reservoirs. How to establish an evaluation system suitable for the characteristics of shale oil is the difficulty of current research. It is necessary to develop new theories and methods especially for the evaluation of oil content, movable fluid and compressibility.

In terms of developing technology, how to improve shale oil recovery is the core challenge. The average recovery rate of shale oil is currently only 5% to 10%, much lower than that of conventional oil fields. This is mainly due to the fact that the complex occurrence state and flow mechanism of shale oil in nanopores have not been fully clarified. In addition, the interaction between fracturing fluid and reservoir and the law of fluid migration under multi-field coupling also need to be further studied.

8. Prospect of Future Research Direction

The future study of shale oil reservoir characteristics should focus on the following directions: The innovation and application of multi-scale characterization technology is an important direction. To develop a multi-scale characterization method that can span nanometer-micron-macro to achieve accurate description of pore structure, fluid distribution and migration paths. For example, high-resolution imaging technology is combined with digital core technology to build numerical models that truly reflect reservoir characteristics.

Digital core technology and artificial intelligence applications will play an increasingly important role. Through digital core technology, the reservoir microstructure can be reproduced virtually and the fluid flow behavior can be simulated. Artificial intelligence technology can mine rules from massive data to optimize development decisions. The application of these new technologies will greatly improve the efficiency and accuracy of shale oil research.

Interdisciplinary integration is an inevitable trend. Shale oil research involves geology, physics, chemistry, mechanics, engineering and other disciplines, which need to break the disciplinary barriers and carry out collaborative innovation. In particular, the combination of micro mechanism research and macro development practice forms a complete research chain from foundation to application.

The research and development of environmentally friendly development technologies is also crucial. In the context of carbon neutrality, how to reduce the environmental impact of shale oil development, improve resource utilization efficiency, and achieve green development will be an important direction of future research.

ISSN: 2688-8645

9. Summary

The study of shale oil reservoir characteristics is the basis of shale oil resource evaluation and development. This paper systematically reviews the characteristics of shale oil reservoirs in terms of geology, physical properties, geochemistry, mechanics and development, analyzes the main problems and challenges in the current research, and looks forward to the future development direction. The study shows that shale oil reservoir has typical characteristics of low porosity and low permeability, nano-scale porosity development, strong reservoir heterogeneity, and is controlled by a variety of geological factors. Future research should focus on multi-scale characterization technology, digital core technology, artificial intelligence applications, etc., in order to promote the efficient development of shale oil. With the advancement of technology and in-depth understanding, shale oil is expected to become an important part of future energy supply and contribute to ensuring national energy security.

References

[1] Zou Caineng, Yang Zhi, Cui Jingwei, et al. Formation mechanism, geological characteristics and development strategies of shale oil [J]. Petroleum Exploration and Development,2013,34(01):1-11.

[2] Zou Caineng, Pan Songqi, Jing Zhenhua, et al. Shale oil and gas revolution and its impact [J]. Acta Petrolei Sinica,2020,41(01):1-12.

[3] Jiang Zexing, Zhang Wenzhao, Liang Chao, et al. Basic characteristics and evaluation factors of shale oil reservoirs [J]. Chinese Journal of Petroleum,2014,35(01):184-196.

[4] Lu Shuangfang, Li Jungan, Zhang Pengfei, et al. Classification and grading evaluation of micro-pore throat in shale oil reservoirs [J]. Petroleum Exploration and Development,2018,45(03):436-444.

[5] Xu Lin, Chang Qiusheng, Feng Lingli, et al. Reservoir characteristics and controlling factors of Permian Fengcheng Formation shale oil in Mahu Sag, Junggar Basin [J]. China petroleum exploration, 2019, 24(05):649-660.

[6] Gao Hui, He Mengqing, Zhao Pengyun, et al. Geological characteristics of Chang 7 shale oil in Ordos Basin and typical shale oil in North America [J]. Experimental petroleum geology,2018,40(02):133-140.

[7] Jia B ,Tsau J, Barati R. A review of the current progress of CO2 injection EOR and carbon storage in shale oil reservoirs[J].Fuel,2019,236404-427.