



Original research paper

Suggestions on the development strategy of shale gas in China[☆]

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Abstract

From the aspects of shale gas resource condition, main exploration and development progress, important breakthrough in key technologies and equipment, this paper systematically summarized and analyzed current situation of shale gas development in China and pointed out five big challenges such as misunderstandings, lower implementation degree and higher economic uncertainty of shale gas resource, and still no breakthrough in exploration and development core technologies and equipment for shale gas buried depth more than 3500 m, higher cost and other non-technical factors that restrict the development pace. Aiming at the above challenges, we put forward five suggestions to promote the shale gas development in China: (1) Make strategies and set goals according to our national conditions and exploration and development stages. That is, make sure to realize shale gas annual production of $20 \times 10^9 \text{ m}^3$, and strives to reach $30 \times 10^9 \text{ m}^3$. (2) Attach importance to the research of accumulation and enrichment geological theory and exploration & development key engineering technologies for lower production and lower pressure marine shale gas reservoir, and at the same time orderly promote the construction of non-marine shale gas exploration & development demonstration areas. (3) The government should introduce further policies and set special innovation funds to support the companies to carry out research and development of related technologies and equipment, especially to strengthen the research and development of technology, equipment and process for shale gas below 3500 m in order to achieve breakthrough in deep shale gas. (4) Continue to promote the geological theory, innovation in technology and management, and strengthen cost control on drilling, fracturing and the whole process in order to realize efficient, economic and scale development of China's shale gas. (5) Reform the mining rights management system, establish information platform of shale gas exploration and development data, and correctly guide the non-oil and gas companies to participate in shale gas exploration and development.

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Keywords: Organic black shale; Shale gas resources; Exploration and development; Development strategy; Key technology; Challenge

1. Introduction

Shale gas refers to the natural gas being exploited from black shale formations, which is rich in organic matter. Shale formations are extremely tight and self-production cannot be realized after drilling. Effective production can be acquired only after the formation of network volumetric fractures in the

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shale beds with the adoption of special technique, such as high pressure [1]. The exploration and development of shale gas are characterized by tight reservoir, high technology demand, rapid production decrease, and long investment recovery period. Through near 30 years of practice and technology research of exploration and development, large-scale developments in USA only began in the recent ten years. The American shale gas production of shale gas in 2015 exceeded $4200 \times 10^8 \text{ m}^3$ [2,3], accounting for 50% of America's total natural gas production, effectively promoting the implementation of “energy independence” of America and also resulting in significant influence on global energy patterns and geopolitics.

By referring the American experience, China initiated exploration and development of shale gas in 2010, and the geological selection, drilling valuation and development testing, have preliminarily proved the abundant shale gas resource in domestic China, with large potentials of exploration and development [4–7]. For five years of exploring, industrial development of marine shale gas have basically realized in Sichuan Basin, and key exploration and development technology and equipment targeting horizons shallower than 3500 m have basically realized domestication. However, even though some findings and tracers at the regions outside of Sichuan Basin have been acquired, no material breakthrough has been realized. In the meantime, with the promotion of exploration and development, the exploration and development potential predication is not yet consistent with the formulation advice of development targets. The current technology and equipment of exploration and development is not adapted to the exploration and development targeting shale gas at deep horizons, with continuously high single-well costs, and the conflicts and challenges, such as the deficiency of management and operating mechanism, are becoming more and more prominent. In order to promote the ordered, healthy and sustainable development, this paper basically clarifies the exploration and development status of shale gas based on the investigation and research of exploration and development of shale gas in China, determining the key problems for the development of shale gas, and development strategy suggestions have been put forward accordingly.

2. Basic characteristics of shale gas in China

2.1. Three types of shale developed in China, with the most types of shale gas in the world, and marine shale gas is the most realistic type

Organic-rich shale types in China are various, including marine, transition, and terrestrial types [4–9] (Fig. 1). Marine shale rocks are mainly distributed in Sichuan Basin and its periphery, the Southern area, is dominated by Middle-Lower Yangtze Region, and the Central and Western area is dominated by Tarim Basin. Upper Ordovician Wufeng Formation to Lower Silurian Longmaxi Formation (Wufeng–Longmaxi Formation) stratum sequence is the focused horizon; transition-phase shale rocks are mainly distributed in Carboniferous–Permian strata in the sedimentary basins, such as Ordos,

Jungar and Tarim basins in the Central and Western regions, and in the Permian strata in the Southern regions; terrestrial shale rocks are mainly distributed in the sedimentary basins such as Songliao, Bohai Bay, Ordos, and Sichuan basins, with the focused strata in Qingshankou, Shahejie and Yanchang Formation and Triassic–Jurassic strata. The exploration and development practice gradually proved that the three types of organic-rich shale rocks are all characterized by basic geologic conditions for the accumulation of shale gas, with relatively big discrepancies. The accumulation conditions of marine shale gas are favorable, with the most realistic exploration and development potential of shale gas.

2.2. Shale gas resources in China is relatively abundant, among which the volume of marine shale gas resources is the largest

Since 2011, different organizations [5–7] carried out predictions on resource potential of shale gas in China (Table 1). In 2011 and 2013, US Energy Information Agency (EIA) evaluated shale gas resources of China twice, and the shale gas resources in place are $144.50 \times 10^{12} \text{ m}^3$ and $134.40 \times 10^{12} \text{ m}^3$, respectively, and recoverable resources are $36.10 \times 10^{12} \text{ m}^3$ and $31.57 \times 10^{12} \text{ m}^3$, respectively, which was ranked the 1st and 2nd place worldwide in the current period. In 2012, the resources in place of shale gas in China is $134.42 \times 10^{12} \text{ m}^3$ and a recoverable resources are $25.08 \times 10^{12} \text{ m}^3$, which is evaluated by *China Ministry of Land and Resource*. The resources in place evaluated by *China Ministry of Land and Resource* is the same as that of EIA (2013) and an obvious discrepancy as to the recoverable resources. In 2012, with emphasis on southern marine shale gas resources, the shale gas recoverable resources in China evaluated by *Chinese Academy of Engineering* is $11.50 \times 10^{12} \text{ m}^3$. In 2015, based on the latest development, the shale gas resources in place in China evaluated by the author (*PetroChina Research Institute of Petroleum Exploration and Development*) is up to $80.45 \times 10^{12} \text{ m}^3$, and $12.85 \times 10^{12} \text{ m}^3$ for recoverable resources. By combination of all prediction results (Table 1), the shale gas resources in place in China is ranged from 80.45×10^{12} to $144.5 \times 10^{12} \text{ m}^3$, and 11.5×10^{12} to $36.1 \times 10^{12} \text{ m}^3$ for recoverable resources.

Judging from Table 1, shale gas resources in China are relatively abundant. However, due to low degree of both exploration and development and understanding degree, the resource prediction discrepancies are relatively big, which is in accordance with the characteristic of oil and gas resources as a matter of fact. Generally, oil and gas resource potential will not be completely determined in one resource evaluation, and may receive continuous improvement with the deepening exploration and development, then gradually being settled. Based on the current exploration and development status of shale gas in China, a total of three agreements may be basically acquired.

Firstly, the marine shale gas resource is relatively determined. The distribution area of marine shale rocks in Wufeng Formation–Longmaxi Formation in southern China is ranged from $10 \times 10^4 \text{ km}^2$ to $20 \times 10^4 \text{ km}^2$, which is characterized

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