Major Understanding and Innovation, Challenges and Potential analysis of Shale Gas Exploration and Development in China

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Abstract. Affected by the success of shale gas development in North America, the Chinese government and major oil and gas producers accurately grasped the development trend of shale gas industry, promoted the pilot tests and introduced policies effectively. In 2018, shale gas production in China was 1.53×10¹⁰ m³. A total of 1000 horizontal wells were drilled. There are some major understanding and innovation achieved, such as stratigraphic division scheme, development characteristics of nanopores, causes of high TOC(Total Organic Carbon) in black shale. The Challenges are discussed. The endowment of shale gas resource is relatively poor. Some key technologies and equipment encounter “bottleneck” and there is poor external environment for development. At last, the paper analyses the development potentials of shale gas in China. The shale gas resources are rich, and shale gas will be the main contributor to the growth of China’s natural gas production. The next step is need to speed up exploration and development, and to increase reserves and production quickly. Also, it is necessary to insist on innovation, offer on-site services, guidance and support, thus providing technical support for realizing new historic leaps of shale gas in China.

Keywords: Shale gas; Major understanding; Wufeng formation; Longmaxi formation; Sichuan basin.

1. Introduction
With the rapid economic development, there is a growing demand for oil and gas in China. In 2019, the external dependence on oil and natural gas reached 72% and 45%, making it difficult to increase the reserves and production of conventional oil & gas. We need to enhance the exploration and development of shale gas and other unconventional oil and gas. Affected by the success of shale gas development in North America, the Chinese government and major oil and gas producers accurately grasped the development trend of shale gas industry and promoted the pilot tests and introduced policies effectively. The potential for shale gas is unclear. The analysis of key problems of shale gas development technology is not accurate, so it is urgent to discuss in detail the progress and challenges of shale gas. Aiming at the
development potential of shale gas, in this paper, development technology progress and challenges of shale gas is discussed. Especially, the non-technical factors are analyzed.

2. Development Trend

2.1. China's Shale Gas Initially Realizes Industrial Development

In 2019, the national shale gas production was \(1.53 \times 10^{10} \text{m}^3\), of which Sinopec's shale gas production was \(7.3 \times 10^8 \text{m}^3\), and PetroChina's shale gas production was \(8.0 \times 10^9 \text{m}^3\). A total of 1000 horizontal wells were drilled, including 400 by PetroChina and 600 by Sinopec. In 2019, the shale gas production was \(8.0 \times 10^9 \text{m}^3\), including \(3.4 \times 10^6 \text{m}^3\) in Changning, \(3.3 \times 10^6 \text{m}^3\) in Weiyuan and \(1.2 \times 10^6 \text{m}^3\) in Zhaotong. In 2019, there were 300 drilled wells and 200 production wells, and a total of 600 wells were put into production in Changning, Weiyuan and Zhaotong. Deepwater slope “sweet spot zone” shale gas theories and horizontal fracturing technologies improved the strategic breakthrough of southern Sichuan ancient marine shale gas-southern Sichuan shale gas province. By the end of 2019, 66 wells have been drilled, including 53 vertical wells, and 13 horizontal wells, in National-level continental shale gas demonstration zone in Yanchang. The fracturing gas testing was performed on 62 wells, including 52 vertical wells and 10 horizontal wells. The bid-winning enterprise and the land department have drilled more than 100 shale gas exploration wells of various types, and gas shows have been seen in Longmaxi formation, Qiongzhusi formation, Qixia formation and Doushantuo formation, but no industrial breakthrough has been achieved[1-2].

2.2. Breakthrough Progress in Resource Exploration at a Buried Depth of 3,500 Meters or Above

There are 15 evaluation wells, buried depth 3500-4000m. The testing production is 4-45 \(\times 10^4 \text{m}^3/\text{d}\). There are 13 evaluation wells, buried depth 4000-4500m. The testing production is 8-22 \(\times 10^4 \text{m}^3/\text{d}\), as is shown in Table 1.

| Block   | Range of buried depth(m) | Number of horizontal well | Testing production \((10^4 \text{m}^3/\text{d})\) |
|---------|--------------------------|---------------------------|---------------------------------|
| Weiyuan | 3500-4000                | 4                         | 4-28                            |
| Dazu    | 3500-4000                | 1                         | 45                              |
| Luzhou  | 3500-4000                | 10                        | 4-30                            |
| Dingshan| 4000-4500                | 3                         | 11-21                           |
| Yongchuan| 4000-4500              | 9                         | 8-22                            |
| Dazu    | 4000-4500                | 1                         | 10                              |

3. Major Understanding and Innovation Achieved

The Wufeng-Longmaxi Formation was stratified and zoned according to the unified standard. The original multiple schemes are not unified with many names, not conducive to communication; It is not connected with the international biostratigraphy and is mainly divided into lithology and sedimentary facies with stratum diachronism. It is necessary to re-establish the stratigraphic division scheme in line with international standards. The importance of biostratigraphic study on black shale is further clarified. There are 13 fossils of graptolite zone in Wufeng formation and Longmaxi formation with distinguishing characteristics. The hirnantia fauna accurately demarcates the boundary of Longmaxi/Wufeng formation[3-4].

There are some characteristics of black shale reservoirs with graptolite. Most of the nanopores are the products of thermal evolution of organic matter. Nanopores are the products of crude oil cracking of marine shale in southern China. The liquid hydrocarbon cracked to form natural gas bubbles in the early stage and finally solidified into pores in the coked pitch[5-7]. The process in which crude oil is heated to produce gas, liquid hydrocarbon cracking is simulated to produce gas and bubbles are solidified into pores. Black is organic matter. The bubble hole is in the Black organic matter, growing bigger.
There are development of honeycomb pores in graptolite fossil. Rhabdosome has a network biological tissue structure, the proportion of organic matter area is as high as 32% and the proportion of surrounding rock area is only 4%. The pores of continental shale are kerogen pores in the eastern margin of Ordos basin. There are mainly humic-type plant cell pores. So there are two distinct forms of nanopores. Nanopores are developed in “asphalt like” formed by secondary cracking of crude oil. Nanopores are developed in lignocellulose in coal-forming plants, as is shown in Table 2.

Table 2. Two distinct forms of nanopores of shale.

| Type                     | Typical area       | Typical horizon           | Kerogen type       | Nanopores type | Causes        |
|--------------------------|--------------------|---------------------------|--------------------|----------------|---------------|
| Marine shale in southern China | Sichuan Basin      | Ordovician-Silurian       | Type I and type II | Gas pores      | Secondary     |
| Continental shale in northern China | Ordos Basin     | Carboniferous-Permian     | Type III           | Cell pores     | Primary       |

The data of Fe components and Mo elements on three typical sections show that the sulfuration and anoxic deposition condition is an important condition for the formation of shale gas sweet spot section. The Qiliao sulfuration is the earliest and lasts the longest. The Shuanghe sulfuration is relatively late and lasts moderately. The Tianba sulfuration is late and lasts the shortest. The sulfuration of Qiliao is the earliest and lasts long. The sulfuration of Shuanghe and Tianba is relatively late and lasts long. In the early stage of diagenesis, dissolution occurs. In the middle stage, illitization produces a large number of siliceous materials. In the late stage, quartz recrystallization occurs, and the recrystallized quartz is arranged in different directions, strengthening the brittleness of shale[8-9].

Shale gas is artificial gas reservoir. There is horizontal well fracturing and industrial platform development. The platform horizontal wells construct underground fracture network. Artificial fracturing builds artificial permeability and forms seep, desorption and diffusion channel, build underground natural gas production system, so sweet spot zone is therefore produced collectively. At present, hydraulic fracture extends 100-150m laterally, extends 15-20m vertically. Lateral permeability within shale is at least 10 times of vertical permeability, and vertical fracture extension is confined by shale lamination.

4. Challenges
The endowment of shale gas resource is relatively poor. In the upper-middle Yangtze region of south China, the tectonic conditions are relatively complex, the shale gas is buried deeply, the reservoir is discontinuous, and the low-grade resources account for a large proportion. Shale gas resources are generally buried deeply and difficult to develop with high production costs. The single well cost of 3500-4000m horizontal shale gas well is 80-120 million yuan. Some shale reservoirs have low gas content after multi-stage structural reconstruction, and the single well production cannot reach the target, so the benefit development cannot be realized. The exploration of shale gas in the land facies and land-sea transitional facies has not made a substantial breakthrough, so it is urgent to innovate in the concept of development and explore an effective development model. Some key technologies and equipment encounter “bottleneck”. The special bit for ultra-long horizontal well drilling is the key equipment for long horizontal well drilling, which mainly depends on foreign companies. The rotary steering tool is the key equipment for drilling 3-5m sweet spot and long horizontal well, and mainly depends on international oil service companies such as Schlumberger and Halliburton to provide technical service. About 30 sets of rotary steering tools have been buried in the well. Due to the lack of high-power fracturing pump truck, the fully soluble bridge plug is mainly imported. Long horizontal section (over 2500m) is drilled in “one trip”, with high displacement, high rotational speed, and high bit pressure parameters combination (displacement up to 30 L/s, bit pressure 200kN, rotational speed 100-200 rpm), which is an excellent and fast drilling technology. High-density completion (cluster
interval 6-15m), closely-cut segment (segment length 30 - 45m), intra-segment steering, high-strength sand adding (over 2.7 t/m) and other large-scale volume transformation technologies[10-11].

There is poor external environment for development. There are some Non-technical factors. Influenced by the operation mode of oil enterprises, the development of shale gas has not reached the local expectation, thus the attitude towards shale gas development has changed. The problem of work hindrance by local people is still serious. It is very difficult to pay compensation and sign for implementation after setting-out work, and the land hand-over time is delayed seriously. The residents of the resource area are demanding. The work is hindered and the road is blocked frequently. The requirements for safety and environmental protection are gradually upgraded. The red line of ecological protection should not be touched, and panic among the surrounding masses and pollution to the natural environment should not be caused.

5. Conclusion

The development prospect is wide for shale gas as the new field of natural gas production growth. In 2018, China’s net import volume of natural gas was 120.4 billion cubic meters and the external dependence was 43%. By 2040, the demand will reach 550-600 billion cubic meters and the external dependence will be 70%. The shale gas resources mainly in the Wufeng Formation-Longmaxi Formation of marine facies are implemented as a whole, with an annual gas production of more than 80 billion. In the middle and upper Yangtze region, for marine facies, the annual production of shale gas is 60-80 billion cubic meters, and for non-marine facies, it is 20 billion cubic meters. In 2030, the production is 50 billion cubic meters: Wufeng-Longmaxi Formation 45 billion cubic meters, and transitional and continental facies 5 billion cubic meters. In 2040, the production is 80 billion cubic meters: Wufeng-Longmaxi Formation 50 billion cubic meters, transitional and continental facies 15 billion cubic meters, and Qiongzhusi Formation 15 billion cubic meters. There are three key points. Strengthen the evaluation on the area selection in deep layers, and explore new areas, new types and non-marine facies. In areas at 3,500 meters or below, focus on optimizing the development technology policies. Between 3500 and 4500 meters, overcome key engineering and technical bottlenecks.

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