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Research progress of shale gas exploration and development in Sichuan Basin

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Abstract

Sichuan Basin is currently the key area for shale gas exploration and development in China, and it is also the most successful area. The future development prospect of shale gas in China has a direct impact on the exploration and development of shale gas in Sichuan Basin. In order to further promote the large-scale and high-efficiency development of shale gas in China, the exploration and development of shale gas in Sichuan Basin is very important under the new situation of carbon peak and carbon neutral target. Therefore, this paper summarizes the basic characteristics of shale gas, summarizes the research status of shale gas at home and abroad and the new progress of shale gas exploration and development in Sichuan Basin, discusses the difficulties and challenges faced by China's shale gas development, and puts forward relevant countermeasures and suggestions. The results show that the Sichuan Basin has a wide range of marine, marine continental transitional and continental sedimentary strata, and there are many sets of organic rich shale strata, which has a good prospect for the development of shale gas. The large-scale and efficient development of shale gas in Sichuan Basin must be based on the sustained and stable production of medium and shallow shale gas and the large-scale construction of deep shale gas. China's shale gas resources have a good prospect and great development potential, but it also contains some key technologies and shortcomings that need to be broken through. It is necessary to continuously innovate and develop new mining technologies, carry out in-depth research on the accumulation mechanism and resource evaluation methods of different types of shale gas, and establish a shale gas geological theory system with Chinese geological characteristics.

Keywords

Sichuan Basin; Shale gas; Exploration and development; Medium shallow layer; Deep layer

1. Introduction

As an unconventional natural gas, shale gas is an important source of non-traditional energy and an important direction of energy substitution in the future. The United States was the first to explore the exploration and development

technology of shale gas. The success of shale gas exploration and development has greatly increased the natural gas production of the United States, and has become the world's largest gas producer[1], and has also changed the world's energy pattern[2]. The exploration and development of shale gas in China is later than that in developed countries in North America, but China is rich in shale gas resources. It is estimated that China's shale gas reserves are about 26×1012 m3, which is equivalent to the reserves in the United States (28×1012 m3), and has good exploration and development prospects.

After more than ten years of exploration and development research and practice[3], shale gas has become the main resource for increasing reserves and production in China's natural gas field. Accelerating the exploration and development of shale gas and increasing the proportion of natural gas in primary energy consumption is the only way to speed up the construction of a clean, low-carbon, safe and efficient modern energy system. It is also an effective way to resolve environmental constraints, improve air quality and achieve green and low-carbon development. At present, in addition to the effective utilization of shallow marine shale gas resources of more than 3500 m, China has a huge amount of resources in marine deep, continental and marine land transitional shale formations. With the maturity of shale gas exploration and development theory and technology, China's shale gas production will rise significantly in the future. Sichuan Basin has become and will continue to be the main battlefield of shale gas exploration and development in China. The exploration and development of shale gas in Sichuan Basin reflects and affects the development prospect of shale gas in China in the future to a large extent, and accelerates the development of shale gas exploration and development in China. Sichuan Basin has always been the most potential area for natural gas exploration and development in China. The large conventional gas fields include Puguang gas field discovered in 2003 and Longwangmiao gas field newly discovered in Anyue in 2012. In the face of the latest situation such as carbon peaking and carbon neutralization targets, it is of great significance to analyze the progress and challenges of shale gas exploration and development in Sichuan Basin in time, and study the strategies to tackle the challenges, so as to promote the large-scale and high-efficiency development of shale gas in China.

2. Basic characteristics of shale gas

Shale gas mainly exists in the state of adsorption and free, and exists in hydrocarbon gas in shale and its interlayer. Shale gas is dry gas under natural conditions, in which methane and nitrogen account for 65% to 95% by volume, and sometimes contain trace amounts of ethane, butane and inert gas. The content of shale gas varies from place to place and from layer to layer in the same place[4]. The formation of shale gas is often the result of the joint action of the two causes. According to the causes, China's shale gas can be divided into marine, land sea transitional and continental

shale gas. Marine shale gas is the main source of shale gas in China. Its development stage is concentrated in the pre Early Paleozoic, and its occurrence places include North China, Southwest China and Northwest Plateau. The marine continental transitional facies shale gas was developed in the Mesozoic and concentrated in Zhungeer, Puguang, Sichuan and Bohai Bay. Continental shale gas is developed in Permian, Triassic, Neogene and Paleogene, and the main occurrence areas include the Qinghai Tibet Plateau, Songliao Basin and other areas in China[5].

In situ retention accumulation is the main mechanism of shale gas accumulation, which is mainly reflected in the migration times in the process of natural gas accumulation. After adsorption, desorption, dissolution and other aspects, it can be divided into the following stages. First, kerogen and oil pyrolysis gas are adsorbed on the surface of shale matrix. Secondly, the surplus natural gas escapes into the nearby pore throat to saturate and accumulate in situ in adsorbed free state. Finally, the supersaturated natural gas migrates to the overlying inorganic pores at the first time, and after saturation, it migrates to the intragranular and intergranular pores for accumulation[6]. The main factors affecting the enrichment and high yield of shale gas reservoirs are as follows: the sedimentary environment rich in organic matter and the high total organic carbon content of shale, which are within the range of effective pyrolysis, can provide a continuous source of gas, the reservoir forming area has well-developed pores and fractures, sufficient storage space, good sealing of reservoir cap rock, and is located in the structural stability zone, and the pyrolysis gas is well preserved after transportation[7].

3. Research status of shale gas exploration and development at home and abroad

According to statistics[8], the recoverable reserves of shale gas in the world are about 4. 56×1014 m3, which is expected to become the most important alternative energy in the 21st century.

The United States is the first country to conduct shale gas research. As early as the early 19th century, the United States discovered the first shale gas well in Appalachia area and successfully obtained shale gas. Since then, shale gas has entered human vision as a new energy[9]. Since 1920, shale gas exploitation in the United States has entered the modernization process, and shale gas enrichment areas have been found in more than 30 regions in 20 continents in the country. Affected by the oil crisis at the end of the 20th century[10], the United States has deepened the research and development of unconventional energy and carried out a series of shale gas exploration and development tests, and the shale gas production has begun to take shape. At the beginning of this century, the United States successively achieved production breakthroughs in shale gas fields such as Barnet, Marcellus and Haynesville. In 2016, the total production of shale gas in the United States reached 4.447×1011 m3, and the shale gas resources achieved leapfrog development. In the

future, the United States will enter the golden age of natural gas production and exploration and development. The continuous exploration, advanced and mature exploration and development technology and the continuous increase of shale gas reserves will increase the amount of shale gas exploration and development in the United States. The successful exploration and development of shale gas has greatly improved the status of oil and gas imports in the United States and accelerated its pace of energy independence[11].

Shale gas exploration in China has great potential. Through research, it is found that the geological conditions of sedimentary basins in most parts of China are similar to those in the eastern United States where a large amount of shale gas is developed, and shale gas reservoirs are well developed. Southern China is the main area for shale gas development, and the Yangtze region in the middle of southern China has better burial and sedimentary conditions, which is a favorable area for shale gas development. The lithology is mainly black shale, and there are eight sets of source rock strata, which are widely distributed, thick, deeply buried, high organic matter, high maturity, and have good exploration and development conditions. These eight sets of strata are Upper Sinian Doushantuo Formation, Lower Cambrian Qiongzhusi Formation, Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation, Middle Devonian Luofu Formation, Lower Carboniferous Hezhou Formation, Lower Permian Qixia Formation, Upper Permian Longtan Formation and Dalong Formation, and Lower Triassic Qinglong Formation. At present, the Sichuan Basin has become the world's second large-scale shale gas production base after the United States, and is the main battlefield for shale gas exploration and development in China[12]. According to statistics, the daily production of shale gas in some parts of the southern Sichuan Basin has reached 4000×104 m3, which has become an atmospheric area of shale gas with trillion cubic meters of reserves and 10 billion cubic meters of production[13].

4. Current situation of shale gas exploration and development in Sichuan Basin

Sichuan Basin is one of the four major basins in China, the largest petroliferous basin in southern China, one of the earliest basins to discover oil and gas resources in the world, and a typical multi-stage tectonic superimposed basin. Over the past 60 years of oil and gas exploration and development in the Sichuan Basin, 120 natural gas fields have been discovered and 110 natural gas fields have been developed. As of 2017, the geological reserves of shale gas in the Wufeng-Longmaxi Formation in the Sichuan Basin have been proved to be 9 210×108 m3, and the production capacity of more than 100×108 m3 has been built. In 2018, the annual output of shale gas was 90.25×108 m3, and China has become the third country in the world to achieve large-scale development of shale gas[14].

Marine shale gas deposits in Sichuan Basin are stable in thickness, large in thickness

and high in organic matter content, which are the key areas of shale gas exploration. The geological resource of marine shale gas in Sichuan Basin is 32.59×1012 m3, and the recoverable resource is 6.57×1012 m3. The geological resource of shale gas in Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation is 26.90×1012 m3, accounting for 84% of the total resource, and the recoverable resource is 5.51×1012 m3. The geological resource of shale gas in the Cambrian Qiongzhusi Formation is 5.69×1012 m3, accounting for 18% of the total resource, and the recoverable resource is 1.06×1012 m3. From the perspective of distribution area, shale gas resources are mainly distributed in East Sichuan and southwest Sichuan, and the shale gas resources of Wufeng-Longmaxi formation are mainly distributed in Fuling area and Pengshui area in Chongqing. Sichuan Basin is rich in matrix rich shale. There are six sets of regional matrix rich shale from top to bottom, including Upper Triassic Xujiahe Formation, Lower Jurassic Ziliujing Formation, Upper Permian Longtan Formation, Upper Ordovician Wufeng Formation-Lower Silurian Longmaxi Formation, Lower Cambrian Qiongzhusi Formation and Upper Sinian Doushantuo Formation. These six sets of organic rich shale are thick, stable in regional distribution, high in organic carbon content and high in maturity, which have good prospects for shale gas resources.

The shallow and medium marine overpressure shale gas area in Sichuan Basin, with a buried depth of 2 500-3 500 m, has built a gas production scale of 200×108 m3/a, in the future, it will be dominated by stable production, which is the cornerstone of the development of shale gas industry. The preliminary evaluation shows that the favorable area for shale gas development in Wufeng-Longmaxi formation with a buried depth of 2500-3500 m is 1.3×104 km2, and the geological resource of shale gas is about 8.0×1012 m3. By the end of 2020, PetroChina and Sinopec had focused on Fuling, Changning, Weiyuan and Zhaotong blocks, and the proved geological reserves of shale gas exceeded 2.0×1012 m3, covering an area of about 2000 km2. The deep marine overpressure shale gas area in Sichuan Basin and its adjacent areas, with a buried depth of 3500-4500 m, has a resource base with an annual shale gas production of more than 300×108 m3, and is the main area of shale gas production growth in the future. The development technology of marine shale gas with a buried depth of 3500-4000 m is basically mature, and it is the main production area during the 14th five year plan. After the breakthrough of effective development technology of marine shale gas with a buried depth of 4000-4500 m, it has the development potential of producing 200×108 m3/a. The ultra deep marine shale gas with a buried depth of more than 4500 m is rich in resources and can be used as a replacement field to maintain stable production in the future.

5. Difficulties and challenges in shale gas exploration and development

China is rich in shale gas reserves, but in the process of exploitation, it is still faced

with problems such as difficult exploitation, high cost and investment, and long construction period. Moreover, the domestic shale oil resource investigation and evaluation system has not been systematically carried out, and the total amount, distribution and understanding of resources are not deep enough.

Horizontal Fracturing and horizontal drilling technology are important technical means in shale gas development. Compared with advanced countries, China still has certain deficiencies in the above two aspects. There are still great differences between China's shale gas reservoirs and the United States' shale gas reservoirs. China's shale gas deposition age is relatively early, and the depth of shale gas reservoirs is basically more than 3000 m. exploration is relatively difficult, and the gas reservoir structure is relatively complex. The United States' shale gas reservoirs are relatively shallow, and the reservoir depth is basically not more than 3000 m, some even only a few hundred meters. We can further strengthen the theoretical research on shale gas accumulation, carry out in-depth research on the accumulation mechanism and resource evaluation methods of different types of shale gas, and establish a shale gas geological theoretical system with Chinese geological characteristics.

Hydraulic fracturing is a method often used in the process of shale gas exploitation in China at present. Large scale hydraulic fracturing requires a lot of water resources, and may also cause the penetration of shale gas and fracturing fluid, resulting in environmental pollution in the leakage area. Develop environmentally friendly and safe drilling and fracturing supporting technologies to reduce the adverse effects of drilling and fracturing on the natural and human settlements.

6. Conclusions

The Sichuan Basin is widely developed with marine facies, marine continental transitional facies and continental sedimentary strata, and there are many sets of organic rich shale strata. The formation and enrichment conditions of shale gas are superior, and the shale gas resources are abundant, which has a good prospect for the development of shale gas. After nearly 10 years of scientific and technological research and exploration and development practice, the understanding of basic geological theory of marine shale gas in Sichuan Basin has made significant innovation. The development technology of shallow marine shale gas with a burial depth of 3500 m and a burial depth of 3500-4000 m has been mature and basically formed. In the next 5-10 years, the shale gas in Sichuan Basin will develop from the stage of large-scale exploitation to the stage of large-scale and efficient development. The large-scale and efficient development must be based on the sustained and stable production of medium and shallow shale gas and the large-scale construction of deep shale gas. Although China's shale gas resources have good prospects and great development potential, it also contains some key technologies and shortcomings that need to be broken through. It is suggested that we should continue to innovate and develop new mining technologies, carry out in-depth research on the accumula-

tion mechanism and resource evaluation methods of different types of shale gas, and establish a shale gas geological theory system with Chinese geological characteristics.

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