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Research Progress on Distribution Characteristics and Development Technology of Shale Gas

Haiguang Hu

Chongqing Business Vocational College, Chongqing 401331, China
807417698@qq.com

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Abstract: The efficient development of shale gas has become the focus of the world. Based on the development status of shale gas in China, the distribution characteristics of shale gas are described, and the current development technologies are analyzed from the perspectives of different burial depths and horizontal wells, respectively. The results show that the horizontal well-staged fracturing technology is the main development technology at present, but with the increasing difficulty of resource exploration, it is difficult to use the technology. In the process of shale gas development, there are some problems, such as the technology can not meet the actual needs, safety and environmental protection are facing challenges, and the development cost is high. Finally, some suggestions are given for the future development of shale gas, which provides theoretical guidance and help for the efficient development of shale gas in the next step.

1. Research Background

With the rapid development of the economy, energy has become the main pillar of the country, which will directly affect the economic lifeline of the country. Since the gradual opening of the shale gas market, the domestic shale gas area has gradually increased, and the implementation of supporting development technology has gradually matured. At present, China's shale gas development has gradually reached the world's leading level, second only to the United States, Canada, and other Western powers in terms of technology and theory, and is the third largest shale gas producer in the world, ranking in the forefront of the world. Compared with shallow shale gas, various geological conditions and process parameters (reservoir burial depth, temperature, pressure, and ground stress) of deep shale gas have changed significantly. There are a lot of problems to be solved in the exploitation process, specifically involving drilling engineering, fracturing engineering, gas reservoir engineering, and other difficult problems. How to develop efficiently, safely, and smoothly brings great challenges to the development of deep shale gas [1]. After shale gas exploitation, because shale gas has the characteristics of low carbon and environmental protection compared with other fossil energy, the development market of shale gas still has a bright future under the trend of international carbon peak and carbon neutralization [2].

In September 2016, the National Energy Administration issued the Shale Gas Development Plan (2016-2020), which proposed that the annual output of shale gas should be $300 \times 10^8 m^3$ by 2020. In 2030, the annual output of shale gas will be $800 \times 10^8 \sim 1000 \times 10^8 m^3$, which also defines the

strategic goal of shale gas development in China [3]. Therefore, exploring shale gas blocks in China, increasing shale gas exploration, research and development of new technologies, and increasing shale gas production are of great strategic significance for ensuring China's energy security.

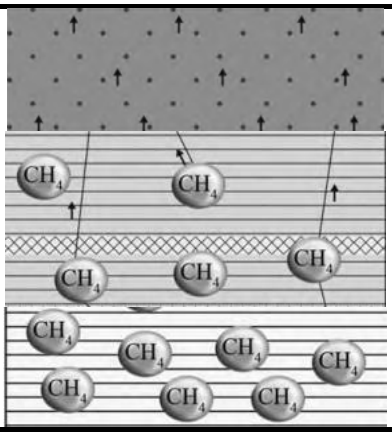
2. Research Status of Shale Gas Distribution and Technology Development

Shale gas is a form of methane gas. After several migrations, it is usually hidden in fractures and voids, stored and preserved for a long time, and gradually evolves into a commercially valuable mixture of natural gas, and the content of shale gas varies with different formations. Shale gas, as a new unconventional natural gas, is difficult to exploit, widely distributed, and rich in global resources. It is gradually changing the overall energy structure and political pattern of the world. The characteristics of shale gas reservoirs and their accumulation and migration process are shown in Table 1 and Table 2.

Table 1: Local characteristic distribution of different types of shale gas reservoirs

type	Scope of mining area	Gas content
Marine	$(10\sim20)\times10^4km^2$	$1\sim6m^3/t$
Phase of transition	$(5\sim10)\times10^4km^2$	$<1m^3/t$
continental	$<5\times10^4km^2$	$0.5\sim2.2m^3/t$

Table 2: Shale gas accumulation, retention, and migration process

Sandstone formation	Within and between grains pore accumulation gas		Secondary migration
Shale rock formation	Inorganic substance pore accumulation gas		Primary migration
	Organic pores collect gas		No transport

2.1. Shale Gas Resource Distribution Status

2.1.1 Distribution of Foreign Shale Gas

In 1821, the first shale gas well in the United States was successfully put into production, which greatly enhanced the potential commercial value of shale gas. Because of its scarcity and difficulty in development, shale gas has gradually become the focus of global energy attention. The development of shale gas in North America started relatively early, and the production of shale gas declined after 2016 due to the influence of technology and other factors. Seeing the commercial value and strategic value of shale gas, Canada has also carried out shale gas development research in China. Canada is the second country in the world to successfully carry out shale gas development, and its understanding and exploitation of shale gas resources are second only to the United States. Latin America has 56 trillion cubic meters of recoverable shale gas reserves, mainly concentrated in Argentina, Mexico, and Brazil. The potential resources of shale gas in Europe are about 14.4 trillion cubic meters, and its development level is still in the initial stage. Shale gas resources in Europe are

mainly distributed in Russia, Poland, Ireland, France and Ukraine [4].

2.1.2 Distribution of Domestic Shale Gas

Shale gas resources are widely distributed in China and the reserves are very abundant. With the continuous innovation of technology and the increase of exploration efforts, the production of shale gas is also increasing year by year, mainly distributed in Sichuan Basin, Tarim Basin, Junggar Basin, Songliao Basin and Yangtze Region.

According to incomplete statistics, the remaining recoverable reserves of shale gas in China are about $3.39 \times 10^{14} m^3$. The content of shale gas accounts for 15% of the world's total. Shale gas formed in different regions and geological structure is different. It mainly includes the following types (Table 3):

Table 3: Distribution of Shale Gas

Type	Distribution area	Developmental stage
Marine shale gas	Southwest, Northwest Plateau, North China	Pre-Paleozoic
Shale gas of marine-continental transitional facies	Sichuan Puguang, Zhungeer and Bohai Bay	Mesozoic era
Continental shale gas	Songliao Basin and Qinghai-Tibet Plateau	Permian, Triassic, Paleogene

2.1.3 Comparison of Shale Gas Geology and Development Conditions between China and the United States

Table 4: Comparison of shale gas geology and development conditions in China and America

Compare the content		China	America
Geological conditions	Construction	Complex, fracture development	Simple, with few fractures
	Type of deposition	Diverse, less effective range of marine facies	Single, mostly marine shale
	Organic carbon content	Low, mainly 1% ~ 5%	Rich, mainly 5% ~ 10%
	Gas content	Low	High
	Degree of thermal evolution	Complex, higher than the sea	Moderate, mainly in the peak stage
Development conditions	Buried depth	Slightly larger, mainly greater than 3500m	Shallow, mainly 2500 ~ 3500 m
	Surface conditions	Complicated, more mountains in the south and less water in the north	It is mainly composed of plains and hills with abundant water.
	Oil and gas pipeline network	Generally, it is underdeveloped, and part of it has no pipe network.	Developed, all over the country

Compared with foreign countries, shale gas in China started relatively late. In the early stage of development, China learned from the development experience of the United States. With the deepening of development and the continuous improvement of its own technology, China has also formed a set of practical development technologies. As shale gas development enters the middle and later stages, shale gas in China and the United States shows different characteristics in terms of development and geological conditions. Compared with the United States, China has a poor

resource base (Table 4 for details) and poor geological conditions, which to a certain extent determines that China should innovate and propose its own development technology in combination with the actual situation.

2.2. Current Status of Shale Gas Development Technology

Due to the special occurrence of shale gas, it is a kind of unconventional oil and gas reservoir, which brings difficulties and challenges to the exploitation, and most of the gas reservoirs need external forces to exploit shale gas. In recent years, scholars at home and abroad have innovatively put forward a series of development technologies based on the actual situation of shale gas exploitation, laying the foundation for the efficient exploitation of shale gas.

2.2.1 Development Technology at Different Burial Depths

(1) Shale gas development technology with burial depth less than 3 500 m

At present, the shale gas development technology in this interval has been relatively mature, and the main technologies include six main technologies[5], namely, comprehensive geological evaluation, development optimization, optimal and fast drilling of horizontal wells, volume fracturing of horizontal wells, factory operation of horizontal wells and efficient and clean production, which gradually realize the large-scale industrial development of shale gas in the middle and shallow layers.

(2) Deep shale gas development technology with burial depth of 3500-4500 m

Based on the geological characteristics of deep shale gas reservoirs and taking a block in Sichuan Basin as the research object, Zeng Yijin et al.[6]put forward the key technologies of engineering operation for shale gas exploitation (drilling speed-up technology, fracture transformation volume technology), which greatly shortened the drilling cycle, improved the single well production and reduced the engineering cost.

2.2.2 Main Body Development Technology of Horizontal Well

(1) Horizontal well-staged fracturing technology

At present, horizontal well-staged fracturing technology is the key technology in the process of shale gas exploitation. Through a series of process transformations, a "giant fracture network" is formed, which is currently popularized and applied in Fuling, Chongqing, Shunan, Sichuan, and other places[7,8]. The main methods are as follows:

1) Increase the number of fracturing stages and reduce the interval spacing; 2) Optimize the content and concentration of fracturing fluid and proppants.

Through the above measures, the goal of transforming reservoir strength and improving shale gas productivity is finally achieved.

(2) Optimized and fast drilling technology for horizontal well

Drilling technology is another key technology for shale gas development, especially for deep formations with poor geological conditions. However, in the process of drilling, there are often some hidden problems (such as balling bit, bit sticking), which affect the efficiency and quality of drilling to a certain extent [9]. In order to solve the above problems, domestic scholars have carried out a large number of scientific research and field practice debugging, focusing on optimizing drilling parameters, drilling tool assembly, etc., to shorten the drilling cycle and ensure the safe construction of shale gas. Through continuous practice and improvement, some gas mines in Sichuan and Chongqing have formed a hybrid ultra-horizontal drilling technology[10]of "wellbore structure design + drilling acceleration tools + directional drilling of horizontal wells + modification of drilling fluid performance", which lays a solid foundation for shale gas development and shale

gas production improvement.

2.2.3 Other Development Technologies

(1) In-fiber monitoring technology [11]. In view of the characteristics of "artificial gas reservoir" of shale gas, PetroChina and Sinopec have successfully introduced optical fiber monitoring technology in the process of shale gas development in Sichuan Basin to evaluate the development effect of artificial gas reservoir of shale gas and optimize the engineering technology, which is an auxiliary technology for shale gas development and provides guarantee for the smooth development of Shale gas.

(2) Big data analysis technology[12]. In view of the heavy workload of shale gas exploration and development, artificial intelligence big data analysis has been gradually carried out in various oilfields to deeply excavate effective information and improve the effect of shale gas development. Big data analysis technology is a relatively advanced artificial skills technology at present. With the help of big data analysis, it can dynamically predict the distribution of shale gas and simulate the trend of production change. It is the "eye of heaven" technology for shale gas development.

2.2.4 Review and Analysis [13]

Based on the above analysis, it can be seen that shale gas development has become the focus of the world. China has proposed a series of development technologies such as horizontal well-staged fracturing and drilling based on the characteristics of shale gas distribution, and has achieved certain results. However, there are still deficiencies in exploration and development, optimization, technology, safety, production, economic budget, and other aspects, facing a severe test.

(1) There is a gap between the existing technology and the actual demand. At present, the technology of shallow shale gas exploitation in China is relatively mature, but with the increase of exploitation depth, the existing technology and the actual site can not be effectively integrated, how to break the technical bottleneck is the focus of the next technical research.

(2) The development process faces the test of safety and environmental protection. The distribution of shale gas is relatively complex, and formation, channeling and other phenomena may occur during exploitation, resulting in water and steam leakage, which may lead to water pollution and ecological problems (Table 5).

Table 5: Environmental problems caused by shale gas

Type of pollution	Development link	Mode of pollution	consequences
Underground pollution	fracturing	Fracturing fluid channeling	Domestic and industrial water is toxic
Surface contamination	Well fracturing	Shale gas leakage	Domestic and industrial water is flammable
Air Pollution	Well fracturing	Leakage of methane	Inflammable and explosive

(3) That cost of the whole development process is high. In the later stage of development, due to the influence of rock heterogeneity and formation physical properties, the difficulty and progress of shale gas development increase, the recoverable reserves are limited, and shale gas exploitation still has the problems of high investment and low efficiency.

3 Conclusions and Recommendations

3.1 Conclusion

By analyzing the distribution characteristics and technical status of shale gas at home and abroad, the problems existing in the process of shale gas development are pointed out, which lays a foundation for the efficient and safe development of shale gas resources in the next step.

3.2 Recommendations

(1) Deep, atmospheric and continental shale gas will be the important replacement areas for shale gas exploration and development in Sichuan Basin and its surrounding areas, and marine shale gas with a burial depth of 3 500 ~ 5 000m will be the focus of later exploitation, and shale gas exploration in Sichuan Basin is expected to achieve greater and rapid development during the "14th Five-Year Plan" period.

(2) Shale geological conditions are complex and special, so in the follow-up development, we can focus on efficient drilling, fracturing, and other technologies, further continue to track the development trend of the world's leading technologies, closely integrate theoretical research with experimental research, and closely integrate basic research with applied research to form deep shale gas suitable for China. It provides a strong guarantee for the scale benefit development of deep shale gas resources.

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