

[Review]

Review on Research and Development of Shale Gas in China

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Shale gas reserves in China are large, although shale gas production is still in its infancy. This paper reviews Chinese national policies and guidelines related to shale gas development, in particular those related to recent progress in the development of shale gas reserves in Sichuan Province and Chongqing since February 2015. In addition, three large-scale R&D projects related to shale gas development, funded by the Government of China, are introduced, and the scope of the work in each project is described.

Key words: shale gas, China, resource, resource development, research and development

Introduction

As energy shortages are becoming more and more serious worldwide, sound strategies for developing a sustainable supply of energy from various sources is urgently required. Shale gas reserves are the largest source of energy on Earth, and have emerged as a promising resource for commercial production.

China consumes large amounts of natural gas; however, domestic production is insufficient to meet demand, and the gap between consumption and production is increasing. Shale gas is expected to fill part of the gap between supply and demand in China in the near future. According to predictions by the US Energy Information Administration (EIA), recoverable reserves of shale gas in China are of the order of 31.6 trillion m³, which is the largest reserve in the world (Wiki, 2015). Thus, the potential for China to contribute towards alle-

viating global energy problems is considerable. This paper reviews activities related to shale gas in China, in terms of research, development, and production.

Distribution and characteristics of shale gas in China

In March 2012, the Ministry of Land and Resources of China (2012) issued a report describing a national survey and evaluation of shale gas resources and criteria for selection of areas favorable for shale gas development and production in China. This report identified 41 basins in five districts in China with abundant shale gas reserves and the potential for shale gas development and production. Of the total shale gas reserves, 68.9% are located in Sichuan, Xinjiang, Guizhou, Hubei, Hunan, and Shanxi provinces and Chongqing municipality. Sichuan Province ranks first, with a total reserve of

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Fig. 1. Distribution of main shale gas reserves in China (modified after Hou et al., 2015).

approximately 27,500 billion m^3 , which is about 20 % of the total reserve. Recoverable reserves of shale gas in Sichuan are predicted to be around 4,420 billion m^3 . Figure 1 shows the general distribution of shale gas reserves in China.

Shale gas in China can be classified into three types: continental shale gas, marine shale gas, and marine-continental-transition shale gas. Marine shale gas is widely distributed in southern China, northern China, and the Tarim Basin, whereas continental shale gas is found mainly in northern China, the Ordos, Junggar, Tuha, Bohai, and Songliao basins. Shale gas reservoir conditions in China differ considerably to those in the US, for two main reasons (Chou, 2013; Gao et al., 2013). First, the average drilling depth to shale gas reserves in China is much deeper than in the US; specifically, the drilling depth to reserves is approximately 3,000-5,000 m in the Sichuan Basin, and is estimated to be approximately 2,000-8,000 m in the Tarim Basin. Second, shale gas reserves in China occur mostly in mountainous regions, and poor transportation networks, constrained well locations, seismic risks, and unevenly distributed water sources, for example in the Sichuan, Tarim, and Junggar basins, etc., add to the risks and development costs of shale gas exploration and production in China.

National policy and guidelines

Despite the technical difficulties associated with shale gas development and production in China, which are caused by the geographic and geological conditions, the Chinese government is taking a much more active role than the US government in planning for the development of shale gas reserves (Hu and Xu, 2013; Tian et al., 2014). Shale gas exploration has been included in China's national strategic planning. The China Shale Gas Development Plan (2011-2015) (National Energy Administration, 2012), issued in March 2012, described, in detail, planned work on shale gas development through to 2015, as well as possible scenarios up to 2020. A shale gas production target was set at 6.5 billion m^3 of shale gas by the end of 2015, and 60-100 billion m^3 by the end of 2020. Moreover, the Chinese government has adopted an R&D program and a funding policy to promote shale gas development. Major R&D projects will be introduced later on.

In October 2013, the National Energy Administration (2013) issued the Shale Gas Industry Policy. The policy reports that the Government of China will encourage companies to apply advanced technologies to improve exploration efficiency, and that the price of shale gas will

be determined by market prices. Imported technologies for shale gas exploration and development will be eligible for tax exemptions. Between 2016 and 2020 (the 13th Chinese five-year plan), the Chinese Government will continue to provide subsidies for shale gas exploration, at a standard rate of 0.3 RMB/m³ over the period 2016-2018, and 0.2 RMB/m³ in 2019 and 2020. In September 2014, a press conference was held in Beijing to announce updates regarding shale gas development. It was reported that up until July 2014, about 400 wells had been drilled, with 130 of those wells being horizontal wells. A major breakthrough in survey and production was achieved in the development of marine shale gas in the Sichuan Basin. Since 2012, a total of 27 wells were under production and the accumulated production of shale gas in the Sichuan Basin was more than 0.6 billion m³.

Meanwhile, local governments have also undertaken shale gas development activity. For example, in March 2015, the Government of Chongqing Municipality (2015) issued the Chongqing Shale Gas Development Plan (2015-2020). Chongqing is in southwest China, adjacent to Sichuan Province, and is a famous mountainous area which, according to the Development Plan, is expected to produce 10 billion m³ of shale gas by 2017 and 20 billion m³ by 2020. As of February 2015, 162 wells had been drilled in the Chongqing area, 94 of which were under operation, with production at approximately 3.8 million m³/day. Similarly, the People's Government of Jiangxi Province (2012) issued the Jiangxi Shale Gas Survey, Exploration, and Utilization Plan

(2011-2020) and the Sichuan Provincial People's Government (2012) issued the Sichuan Shale Gas Development Plan (2013-2015).

Practical development of shale gas in China

Some typical shale gas wells and shale gas pipelines

The first shale gas well developed in China, known as "Wei 201", was drilled in Weiyuan, Sichuan Province, in 2009. At the same location, the first horizontal well, named "Wei 201-H1", was completed in April 2011; the drilling depth of this well was 2,836 m. Multi-stage hydraulic fracturing was successfully conducted to produce shale gas in July 2011. The first commercial production started in 2011 from the "Ning 201" well, located in Yibin, Sichuan Province.

Drilling of the first marine shale gas well ("Jiaoye 1HF", located in Chongqing) by the Sinopec Exploration Southern Company commenced on 14 February 2012 and was completed on 16 September 2012. This well is 3,654 m deep and has a horizontal length of 1,008 m. Hydraulic fracturing was successfully performed in "Jiaoye 1HF" between 7 and 24 November 2012, and choke testing was completed over the period 28 November-11 December 2012. The well is now under commercial exploitation. In the same area, another well, named "Jiaoye 6-2HF", was brought into production on 29 September 2013; as of 6 September 2014

Table 1. Characteristics of typical shale gas wells in Sichuan Province, including drilling speeds in horizontal wells.

No.	Well	Depth (m)	Horizontal well	
			Length (m)	Drilling period (days)
1	Wei 201-H3	3,647	738	149
2	Ning 201-H1	3,790	1,045	147
3	Ning H3-1	4,010	1,000	65
4	Ning H3-2	3,877	1,000	64
5	Ning H3-3	3,784	1,000	63
6	Ning H2-2	3,786	1,200	76
7	Ning H2-3	3,503	1,010	70
8	Ning H2-4	3548	1000	71

Source: Sichuan Provincial Development and Reform Commission (2014)

(after 342 days of production), 0.1 billion m³ of shale gas had been produced under constant pressure conditions.

Table 1 shows the main shale gas wells in Sichuan Province. Well depths are approximately 3500-4000 m. Drilling speeds in horizontal wells have been greatly improved in recent years (2009-2015), from 4.95 m/day to 15.87 m/day; the time to drill a 1000-m-long horizontal well is now only about 2 months.

In March 2015, it was reported that shale gas had been successfully developed in Jianshi, Hubei Province. Shale gas was found at a depth of only 500 m. Test results on samples showed that the total gas content is expected to be 1.85 m³/ton. On this basis, it is estimated that rich reserves of shale gas are present in this area.

Meanwhile, shale gas pipelines are under construction. In May 2015, in the Changning-Weiyuan demonstration plot, three operating pipelines yielded an average shale gas output of about 1.5 million m³/day. In April 2015, the first shale gas pipeline in Chongqing was completed, with a total length of 136.5 km, diameter of 1.016 m, design pressure of 10 MPa, and design transportation capacity of 6 billion cm³/year. This pipeline can transport shale gas to areas in the east of China, such as Shanghai, Zhejiang, and Jiangsu, where the demand for natural gas is especially high. In Chongqing, plans are underway to construct 889 km of pipeline (in 8 pipelines) for shale gas output by the end of 2017, and another 1,169 km (in 11 pipelines) by the end of 2020. The target pipeline transport capacity for China is 19.4 billion m³/year by the end of 2020.

Technology development

By the end of 2014, a total of 400 wells had been drilled in China, and the total annual shale gas production was 1.3 billion m³, representing a 5.5% increase over production levels in 2013. In addition, the construction cost of a horizontal well decreased from 100 million to 50-70 million RMB, and the construction period was shortened from 5-7 months to 2-3 months during this time. Thus, although the domestic technologies available in China to facilitate shale gas development are improving, production in 2014 still accounted for only

0.73 % of total Chinese natural gas consumption.

Domestic technologies in China are now available for drilling shallow horizontal wells and conducting multi-stage hydraulic fracturing to depths of up to 3,500 m. China is the third country in the world, following the US and Canada, to have conducted shale gas exploration using domestic technologies. Moreover, China has made major breakthroughs in terms of surveying and assessing shale gas reserves, and developing equipment for continuous hydraulic tubing operations, bridge plugs, etc. A new type of fracturing truck, with a capacity of 3,000 kW and a maximum pressure of 140 MPa, was developed in China in 2013; this was the world's first truck of this size. In 2015, the first smart gas gathering station was put into continuous 24-hour operation. Such automation has improved production efficiency, and will help to meet the needs of large-scale development and production of shale gas in the near future.

Development plan in the near future

The third round of shale gas bidding will take place in the near future (not fixed yet). The Chinese government encourages collaboration between domestic and foreign companies regarding the advanced technologies associated with shale gas exploration, and this represents a valuable opportunity to promote international collaboration in the field of shale gas development. Figure 2 compares natural gas production and predictions among the US, Canada, and China by ASIACHEM consulting. They forecast that total global shale gas production will be 429 billion m³ by 2020, and 7 % of this will come from China, so that China will become the second biggest producer of shale gas behind the US. Until 2020, except in the US, global shale gas development will remain in its developmental stages. However, over the period 2020-2030, the world will enter into a period of rapid development, and between 2030 and 2040, the period of mature development will commence.

Main ongoing R&D projects

The Government of China has provided ample R&D support for shale gas production, and a large number of

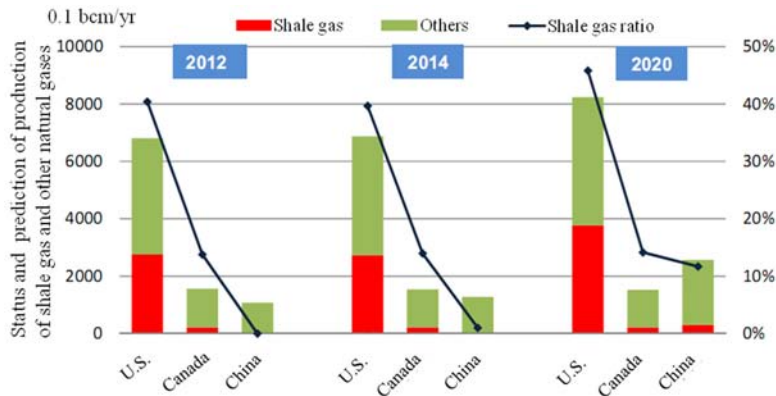


Fig. 2. Comparison of natural gas production from shale gas and other sources and the ratio of shale gas to other gas sources (values shown on right axis) in three countries with well-developed shale gas reserves, for the years 2012, 2014, and 2020 (Source: ASIACHEM).

R&D projects have been funded. Three typical R&D projects are introduced below.

“Fundamentals of Development of High-Efficiency Shale Gas/Oil Production”

This is a major project funded by the National Natural science Foundation of China (NSFC). The total research period is 5 years (2015-2019). The principal work includes: (1) nonlinear engineering geology mechanics of shale gas and prediction theory; (2) mechanisms of dynamic random crack control in shale and new concepts in fracturing theory; (3) multiple-scale seepage characteristics of shale gas/oil and relevance to exploration; and (4) theories of safe drilling for shale gas/oil under multiple coupling conditions.

The project includes five research units involving four universities and one institute: China University of Petroleum (Beijing), China University of Petroleum (Hua-dong), Northeast Petroleum University, Southwest Petroleum University, and China Petrochemical Corporation. Research Institute of Petroleum Engineering. The research team is responsible for some of the most advanced petroleum engineering research in China.

“Fundamentals of Development of High-Efficiency Enhanced Shale Gas Recovery using Supercritical CO₂”

This project is supported by a grant from the “973

Program”, a basic research program initiated by the Government of China for the purpose of achieving a technological and strategic edge in various scientific fields. Wuhan University, the leading research organization, was ranked among the top five universities in China in 2014. The total research period is 5 years (2014-2018).

The main focus of this project is the development of survey methods and evaluation standards for premier shale gas reservoirs, hydraulic fracturing mechanisms in shale gas reservoirs using supercritical CO₂ injection, dynamics of displacement of shale gas by CO₂ injection under condition of multiple fields, and safety evaluations for enhanced shale gas recovery by supercritical CO₂ injection. The research consists of six sub-tasks: (1) prediction and characterization of premier shale gas reservoirs; (2) rock fracture and well-hole control theory using supercritical CO₂ injection; (3) mechanism of fracturing and enhanced permeability of shale using supercritical CO₂ injection; (4) competitive adsorption dynamics of CO₂ and shale gas; (5) multi-scale and multi-field coupled seepage theory for shale gas replacement by CO₂; (6) key technologies and safety assessment methods for enhanced shale gas recovery using CO₂ injection.

“Fundamental Research on Development of Shale Gas Reservoirs”

This project is funded by the NSFC, also for a 5-year

research period (2013-2017). The main goals are: micro- and nano-scale fluid mechanics of shale gas; crack propagation in shale by artificial fracturing; and macro fluid mechanics of horizontal well fracture networks under staged fracturing of shale gas reservoirs. The project is conducted mainly at the China University of Petroleum (Huadong) (see Yao et al., 2013 for details).

In addition to the major goals noted above, the project also involves many small- and medium-sized research projects funded by local governments, especially in regions with high shale gas potential. The scope of the work involves a variety of topics, including reserve surveys, seismicity evaluations, and environmental assessments. Moreover, the National Energy and Shale Gas R&D Experimental Center was founded in July 2010; the center has focused on various testing technologies related to shale gas development.

Summary

Recently, China has made tremendous progress in the development and production of shale gas, and fundamental research on shale gas exploration and development is ongoing. The shale gas industry in China has reached the stable commercial production stage, despite numerous problems and challenges. Notably, we suggest that Korean shale gas R&D programs and policies be updated based on information and activity related to the Chinese shale gas industry.

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