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Research Article

Prediction of marine shale gas production in South China based on drilling workload analysis☆

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Abstract

The marine shale gas resource in South China is abundant, but the existing conventional methods cannot meet the needs of predicting the future production development of shale gas. With the marine shale of the Lower Silurian Longmaxi Fm in this region as an example and based on its development potential, the development features of the existing shale gas resources were analyzed. It is considered that the Longmaxi shale gas accumulation zones in the Sichuan Basin and its neighboring areas contain resources of about 17.4×10^{12} m^3 and recoverable resources of about 2.9×10^{12} m^3. In particular, the shale gas above 3500 m underground is the main body for recent development targets, with a potential production scale about 300×10^8 m^3. On this basis, the development features of foreign and domestic shale gas wells were studied and the drilling workload analytical method for the prediction of shale gas production was established: (1) the initial production of a single well can be used to characterize the productivity of the shale gas well, and its test production is approximate to its initial production. Due to the similarity of decline rate among shale gas wells, the single-well estimated ultimate recovery (EUR) value of a single well can be roughly speculated from its initial production, thus the production scale of a shale gas field can be speculated according to the analysis of drilling workload; (2) currently, the expected test production of South China marine shale gas is 17.6×10^4 m^3/d, and the predicted single-well EUR value is roughly 1.5×10^8 m^3. It is concluded that the marine shale gas in South China represents high initial production of a single well, high declining rate, longer production cycle and the drilling workload is closely related with the production of a shale gas field. Therefore, the analysis of drilling workload shows better applicability to the evaluation of shale gas production. Based on this method, the shale gas production of the Sichuan Basin and its neighboring area in 2020 was estimated to be about 200×10^8 m^3.

Keywords: South China; Marine shale; Early Silurian; Shale gas; Estimated ultimate recovery (EUR); Drilling workload; Declining rate; Initial production of a single well; Production

The US "shale gas revolution" basically enables its self-sufficiency of natural gas. The shale gas production in 2015 reached 4250×10^8 m^3, accounting for 56% of the country's total natural gas output. As a result, its external dependence fell from 16% in 2000 to 1% in 2015 [1,2]. With the inspiration of this "shale gas revolution", China has made great progress in the exploration and development of shale gas during the period of "12th Five-Year Plan" (2011–2015). The development technology for shallow shale gas with burial depths less than 3500 m became mature, and effective scale development of shale gas was carried out in Jiaoshiba, Changning and Weiyuan, Zhaotong and other blocks. In 2015,

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China's shale gas production was over 45 × 10^8 m^3. Since China's shale gas production started late, the existing conventional methods cannot meet the needs of future production development prediction of shale gas. In this paper, after an analysis of the resource potential of shale gas, relevant engineering technologies and technical & economic characteristics of shale gas, the production prediction model of drilling analysis was proposed depending on the production characteristics of shale gas wells. Finally, the scale of shale gas production in different conditions was analyzed, in order to provide a reference for China's shale gas industry policy, planning, decision-making and development.

1. Development potential of shale gas resources in China

1.1. Shale gas resources of the Wufeng–Longmaxi Fm in the Sichuan Basin and its adjacent areas

According to the statistics of the Ministry of Land and Resources, China's original shale gas in place is 134 × 10^{12} m^3 and recoverable resources are 25 × 10^{12} m^3; especially in South China, the recoverable resources of marine shale gas reach 8.82 × 10^{12} m^3 [3,4]. Through the exploration and development during 2011–2015, China preliminary realized the effective development of shale gas resources in the Upper Ordovician Wufeng Fm–Lower Silurian Longmaxi Fm in the Sichuan Basin and its adjacent areas. According to the current development of shale gas, the Weiyuan, Changning and Zhaotong blocks in the South Sichuan tectonic stable area of the Sichuan Basin and the Jiaoshiba block in the relatively stable area are the main targets of shale gas development [3,5–7]. By the end of 2015, China's proven shale gas reserves were 5441.29 × 10^8 m^3, including 3805.98 × 10^8 m^3 in Jiaoshiba block and 1635.31 × 10^8 m^3 in Changning, Weiyuan and Zhaotong blocks. As evaluated according to the current shale gas exploration level, the shale gas enrichment areas with burial depths less than 4500 m in the Wufeng–Longmaxi Fm in the Sichuan Basin and its adjacent areas is about 4 × 10^4 km^2, with resources more than 17 × 10^{12} m^3. Especially, the shale gas enrichment areas with burial depths less than 3500 m is 1.5 × 10^4 km^2 with resources about 7 × 10^{12} m^3. Assuming the recovery rate of shale gas with burial depths less than 3500 m is 20% and the recovery rate of shale gas with burial depths between 3500 and 4500 m is 15%, the recoverable shale gas resources are estimated to be about 3 × 10^{12} m^3; specifically, the recoverable resources of shale gas with burial depths less than 3500 m are 1.4 × 10^{12} m^3, and the recoverable resources of shale gas with burial depths between 3500 and 4500 m are 1.6 × 10^{12} m^3.

1.2. Development potential of shale gas resources

In Jiaoshiba, Changning, Weiyuan, Zhaotong and other blocks in the Sichuan Basin and its adjacent areas, commercial development has been achieved, but shale gas is still in its initial stage of development. The development potential of shale gas resources can only be evaluated through a comparison the with typical shale gas fields in the United States. Compared with the reserves and production growth of Barnett, Haynesville and Marcellus shale gas fields, when the reserve–production ratio is 10–20 [8,9], gas field production can achieve a rapid growth. In view of the low level of shale gas exploration in China, given the recoverable part as 50% of shale gas resources with burial depths less than 3500 m and as 40% of shale gas resources with burial depths between 3500 and 4500 m, their proven recoverable reserves are expected to be 6850 × 10^8 m^3 and 6280 × 10^8 m^3, respectively. Assuming the stable production time is one to two decades, the shale gas production scale is estimated to be around 600 × 10^8 m^3 (Table 1).

2. Characterization methodology of shale gas well productivity

The evaluation of shale gas well productivity is the basis of shale gas production forecasting. The initial production of a single well (the average daily production in the first month after the production has reached the peak), the declining rate and the estimated ultimate recovery (*EUR*) of the single well early production are the main indicators for the evaluation of single-well production of shale gas wells.

2.1. Single well productivity can be characterized with its initial production

According to the analysis of typical well decline of typical shale gas fields in the USA, the decline rate of typical wells in each shale gas field remains in a certain interval, and there is a

Table 1
Comparison of development parameters between the shale gas in the Sichuan Basin and its adjacent areas and the typical shale gas fields in the USA.

Main parameters	Shale gas enrichment area of the Sichuan Basin and its adjacent areas			Marcellus shale	Barnett shale	Haynesville shale
Burial depth/m	1000–3500	3500–4500	Total (1000–4500)	600–3000	1200–2500	3000–4300
Original gas-in-place/10^{12} m^3	6.87	10.5	17.37			
Recoverable resources/10^{12} m^3	1.37	1.57	2.94	8.50	2.66	2.20–6.10
Recoverable percent	50%	40%	45%			
Estimated recoverable reserves/10^8 m^3	6850.0	6280.0	13130.0	18377.7	7362.4	4559.0
Reserves-to-production ratio	20	20	20	13.8	16.7	8.8
Gas recovery rate	0.440%	0.290%	0.365%			
Potential production scale/10^8 m^3	300	300	600	1330	440	520