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Research article

How to solve the technical problems in CBM development: A case study of a CBM gas reservoir in the southern Qinshui Basin

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Abstract

The low average single-well production, resulting in low economic benefit, has become the main bottleneck of CBM development in China. In view of this issue, through case study of a CBM gas reservoir in the southern Qinshui Basin, we summarized the present status of CBM technology and development there and also pointed out some major problems in CBM development: (1) the engineering technology for the CBM development needs to adapt to the particular geological characteristics; (2) a large number of inefficient zones still exist in mature blocks in the southern Qinshui Basin; (3) single-well production can not be effectively enhanced only by increasing the fracturing scale; (4) the production of multi-lateral wells is higher, but the fulfillment rate of production capacity overall is still low; and (5) on-site management lacks scientific evidence. On this basis, we present the following suggestions for subsequent coalbed gas development: (1) the production construction mode should be changed, and the fulfillment rate of production capacity construction should be improved; (2) CBM geological research should be improved and well types and locations should be designed reasonably and scientifically; (3) main technologies should be built in a dialectical thinking mode; (4) horizontal well design should be optimized to improve the applicability of relevant technologies; (5) fracturing mode should be changed to improve single-well production; and (6) the drainage technology should be changed to improve economic efficiency.

Keywords: China; CBM; Single-well production; Development efficiency; Dialectical thinking mode; Horizontal well; Fracturing; Desorption pressure; Qinshui Basin

1. Introduction

The average single well output of CBM in China is lower than that in the USA. As of December 2012, about 38000 coalbed methane wells had been drilled in the USA, with an average daily gas rate per well of over 3632 m^3. In contrast, as of December 2013, more than 14000 coalbed methane wells had been drilled in China, with an average daily gas rate per well of about 572 m^3 in that year, and all the traditional multilateral horizontal wells and U-shaped wells did not reach the expected output. The low average single well output has become a major bottleneck for the development of CBM industry in China. Since the CBM resources objectively exist in China, the main reason of low output lies in technical issues. Therefore, how to increase the single well output and improve the development benefit is a technical issue which needs to be unraveled for the sound development of CBM industry of China.

2. Overview of CBM development in the southern Qinshui Basin

The exploration and development of CBM in the southern Qinshui Basin by PetroChina Huabei Oilfield Company (hereinafter referred to as Huabei Oilfield) has been constantly

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deepened since 2006. At present, the average daily gas rate per well is 1430 m^3 in Fanzhuang wellblock, and the output keeps an uptrend on the whole; whereas the average daily gas rate per horizontal well is about 5000 m^3 in the Qinshui Basin, laying a solid foundation for the development of CBM industry.

2.1. Engineering technology is not adaptable for the changes in geological characteristics

A series of engineering technologies supporting the development of coalbed methane have been established by Huabei Oilfield after several years of practices. Fracturing technology with “controlled fluid volume, variable injection rate and active water” is adopted in cluster (vertical) wells. “Continuous, gradual, stable and long-term” policy is adhered to in the management and control of water drainage and gas recovery; different drainage and recovery regimes are established by taking the exit point, desorption point, gassing point and stable rate point as control nodes; and “5-stage, 3-pressure and 4-point” drainage and recovery method and intelligent controlled drainage and recovery technology centering on bottom hole flowing pressure (BHFP) have been formed.

The same series of technologies were adopted in the expansion project of Zhengzhuang and Zhengbei Blocks. However, due to the different geologic parameters of blocks, compared with Fanzhuang Block, the average single well gas rate was far behind the designed index at the same stage, which shows that the changes in geological characteristics of coal seam have a great influence on the output, and the engineering technologies should adapt to the basic features of the major stimulated objects.

2.2. There are still a great number of inefficient zones in mature blocks

Most single vertical wells enter production plateau after 12−18 months of water drainage in the Fanzhuang wellblock where the development has already been mature; whereas most wells in other vertical wellblocks put into production over the years enter production plateau in the third year, only most single wells in vertical wellblocks put into production in 2006 enter production plateau in the fifth year, and still on the rise. Currently, the Fanzhuang wellblock is at a stable gas production stage on the whole, but there are still approximately 1/3 inefficient wellblocks where the single well output is still far below the expected one. The large differences in single well output in the area decrease the development benefit of the gas field.

2.3. Single well output is not effectively improved by increasing fracturing scale

The permeability of high-rank coal seams in the southern Qinshui Basin is low. Therefore, the vertical wells of coalbed methane there are put into production after hydraulic fracturing. Through imitation, optimization and innovation, reservoir stimulation technology in which active water fracturing predominates has been established. After three times of technological change from small-scale, large-scale to super large-scale fracturing, the fracturing fluid volume was gradually increased from 300 m^3 in 2006 to nearly 1000 m^3 in fracturing test in 2013. However, the incremental gas per day was not proportional to the change in reservoir stimulation, the production response failed to reach the desired rate, and the single well output was not effectively improved (Fig. 1). Analysis shows that the causes are mainly as follows:

1) The present coal seam fracturing technological design is based on unclear understanding of such control factors as mechanical property of coal reservoirs, fissure systems, heterogeneity and effect of crustal stress on induced fractures, so it is not adaptable to the requirements of coal seam geology, and cannot form an effective “reticular fracture” system. It can be seen from the basic physical property parameters of coal seam (Table 1) that its basic features are obviously different from those of conventional sandstone, which means that only wide cracks can be created, but long cracks cannot be created by fracturing, and the range connected by fractures is also different from that of conventional sandstone [1]. Therefore, the present fracturing technology applied in coalbed methane development is nothing but a treatment to the nearby wellbore zone, which improves the physical property of coal seam around the well bore.

2) While improving physical property of coal seam around the well bore, reservoir fracturing brings about three disadvantages: ① it increases the formation pressure, which is inconsistent with the blowdown desorption gas production mechanism of coalbed methane, so this may cause large reduction in drainage and recovery efficiency; ② because a large amount of fracturing fluid is squeezed into the coal seam, there is more and more extraneous water in it, and water drainage time correspondingly inceases, which reduces the recovery efficiency; and ③ the desorption pressure is reduced in some areas; relevant experiment proves [2] that in the regions with low water saturation, after the extraneous water enters the microscopic pores of coal seam beyond the proppant, affected by electrostatic force, the water molecule is adsorbed by clinging to methane; in this way, the methane molecule would suffer from double action of electrostatic force and adsorption force, and be more difficult to be

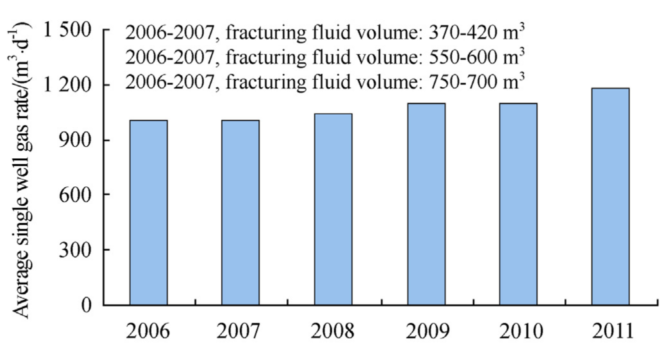

Fig. 1. Variations in average single well gas rate over the years.

Table 1
Young's modulus and Poisson's ratio of different lithologies.

Lithology	Young's modulus/GPa	Poisson's ratio	Lithology	Young's modulus/GPa	Poisson's ratio
Mudstone	2.84	0.28	Tight sand	7.02	0.23
Coal	0.90	0.33	Limestone	6.74	0.24
Packsand	5.82	0.25			

desorbed; and finally, low desorption pressure zone would form beyond the proppant.

Based on the above analysis, currently the hydraulic fracturing of coal seam in vertical wells is not the most effective technology for the development of coalbed methane.

2.4. Single well output of a multilateral horizontal well is higher, but the overall productivity is still lower than expected

Most of the multilateral horizontal wells up to now fail to reach the expected yield. Although the highest daily gas rate per well of some multilateral horizontal wells exceeded 6×10^4 m^3, and was still 4×10^4 m^3 after being in production for 6 years, with a cumulative gas production of nearly 1×10^8 m^3, far higher than the output of vertical wells. But the proportion of high-yield wells is low on the whole, and the proportion of inefficient wells is higher (Table 2).

Because open hole completion is adopted for all the multilateral horizontal wells drilled so far. Completion engineering cannot guarantee a clear and free-of-obstruction borehole. For lack of effective treatment measures like monitoring, maintenance and stimulation, management and control of the open hole section becomes difficult. A good many difficulties have been brought about by open hole completion, usually resulting in low success ratio. However, it can be seen from the advantages of horizontal wells in the development blocks that once breakthrough is made in completion technique, the horizontal well would play a decisive role in the development of CBM industry.

2.5. Field management and control are void of scientific basis on the whole

The present principle for management and control of coalbed methane drainage and recovery is "stable, continuous, gradual and slow". The core of water drainage blowdown of coalbed methane is water drainage; however, as to the questions like how to discharge more water in a short period before the desorption pressure is reached, how to enlarge the radius controlled by pressure drop and guarantee steady supply of gas, there lacks scientific control basis to date.

From the perspective of improving reservoir property, it needs to further verify if too slow drainage and recovery velocity can improve reservoir permeability. Based on the fast and slow drainage test results of Well 17-6 (Table 3), proper fast drainage improved reservoir permeability. However, the improvement of reservoir property by either fast or slow drainage has no theoretical support so far.

3. Consideration and suggestions concerning the future CBM development

3.1. Productivity construction mode should be changed to improve productivity construction efficiency

Productivity construction mode of coalbed methane in the past is basically overall implementation. However, because the gas-bearing and physical properties of coal reservoirs are not uniformly distributed, instead, they change with the variation in structure and sedimentation, this productivity construction mode often results in many low-yield and inefficient zones. Under the existing technical conditions, CBM enrichment and high-yield zones should be developed first, then the inefficient zones with the progress of technology, and gradually form a productivity construction mode from point to section and then to zone, so as to improve the development benefit.

3.2. Geologic research should be improved and well location and well type should be scientifically designed

CBM development practices at home and abroad prove that coal seams, whether in high or low coal rank, have material foundation for gas storage, and the better the reservoir property, the more likely the CBM will reach high production. The output of coalbed gas fields with the same enrichment type is controlled by their physical properties, which has been proved by the CBM development in Chengzhuang, Zhengcun and

Table 2
Output statistics of multilateral horizontal wells in each block.

Daily gas output/m^3	Block F1-2		Block F-C1		Block Z2-2		Block Z3	
	Number of wells	Daily production per well/m^3	Number of wells	Daily production per well/m^3	Number of wells	Daily production per well/m^3	Number of wells	Daily production per well/m^3
0	13				14		2	
1−1000	17	438			14	449	1	862
1000−2000	3	1232			7	1325		
2000−5000	11	3328	1	4348	7	3220		
5000−10000	5	7205			3	6212		
>10000	7	16903	3	27114	1	15804		
Mean value		3609		21423		1577		287

Table 3
Fast and slow drainage test results of Well 17-6.

Test	Well opening time/d	Shut in/d	Produced water/m^3	Daily water flow rate/m^3	Flowing pressure drop/MPa	Post-fracturing permeability/mD	Flowing differential pressure/MPa	Fracture half-length/m	Pressure boundary/m
1	7.5	40	34	4.48	1.84	1.98	4.27	125	305
2	17.0	41	144	8.46	4.9	2.57	5.58	125	356

Fanzhuang Blocks of Huabei Oilfield. Moreover, the development status of other CBM development blocks in China and low-rank coal in Surat and Bowen Basins of Australia also confirms that physical property is the factor affecting high production.

Blocks with different geologic conditions are different in the difficulties to get high production, so proper development techniques are needed for support, which cannot be copied simply. The means to improve reservoir property in the same block mainly include fracturing and horizontal well drilling. There is still no effective solution to the disadvantages existed in the present fracturing mode. So horizontal well drilling should be as perpendicular as possible to the fracture direction, for only by connecting more fractures, can the permeability be improved. Geological content in the following three aspects should be studied: ① variation in regional stress, so as to figure out the occurrence of cracks; ② distribution pattern of regional structures, so as to clarify the fault systems; and ③ regional gas-bearing patterns, so as to find out CBM enrichment zones. On this basis, the well types should be scientifically designed to improve the geologic design level.

3.3. Major technologies should be established in a dialectical thinking mode

Because the output of coal seam is low due to its low permeability, the strength of fracturing stimulation should be increased, which is a thinking mode fettered by conventional petroleum development; currently, it is very hard to improve the CBM production in the development blocks where fracturing is taken as the major technology, which is no other than the embodiment of this issue.

When it comes to improving the single well output of coalbed methane, the advantages and disadvantages of present fracturing technology should be considered first. The advantage is that fracturing improves the permeability of nearby wellbore zone; whereas the disadvantages are as follows: firstly, fracturing enhances the formation pressure, which is contrary to the blowdown requirement of CBM development; and secondly, substantial fracturing fluid entering the formation, reduces the desorption pressure, shortens the blowdown radius, and lowers down the development efficiency. Therefore, in the exploitation of coalbed methane, dialectical thinking mode should be taken to work out major technologies by fully considering the main geologic features such as organic components, and the engineering technology should be shifted from the past fracturing stimulation to the mode of effectively opening up of formation with horizontal wells.

3.4. Horizontal well design should be changed to improve the applicability of relevant technologies

The investment of multilateral horizontal wells is too high (over RMB 10 million a well), but the success ratio is too low. The horizontal well design in the future should focus on solving the following issues: firstly, high investment, which may be solved by changing complicated well types into simple ones; secondly, disadvantages existed in open hole completion, support string should be run in horizontal section to make workover and maintenance possible.

Periodic success has been achieved in horizontal well Ping 1, an L-type horizontal well tested on site and designed as per the geologic design concept of perpendicular to fracture (Fig. 2): with a coal seam length of 555 m revealed and the output of the well rising to 2500 m^3 in 4 months without fracturing. Compared with multilateral horizontal wells, it possesses advantages in investment, maintenance, operation, and management and control. It may be more suitable for special rock mass such as coal seams to adopt horizontal wells to connect fractures.

3.5. Single well output should be improved by changing fracturing stimulation mode

Great efforts should be made to solve the disadvantages of present fracturing mode in exploiting the coalbed methane, and the second generation of low-damage active water fracturing should be perfected gradually.

There are essential differences between the exploitation of coalbed methane and that of conventional oil and gas, and the former has two distinctive characteristics: ① only by blowdown, can desorption and gas production be realized; and ② a large amount of extraneous water entering the coal seam will

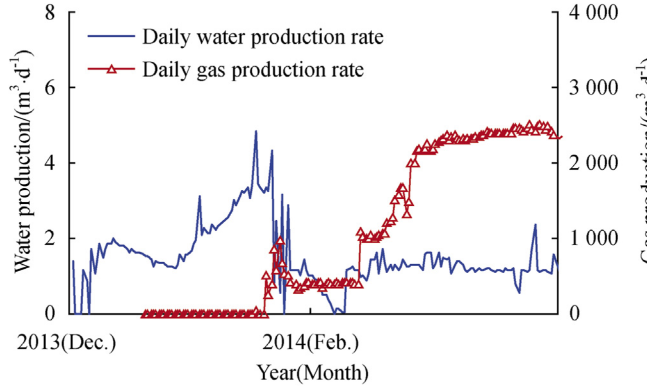

Fig. 2. Production curves of horizontal well Ping 1.

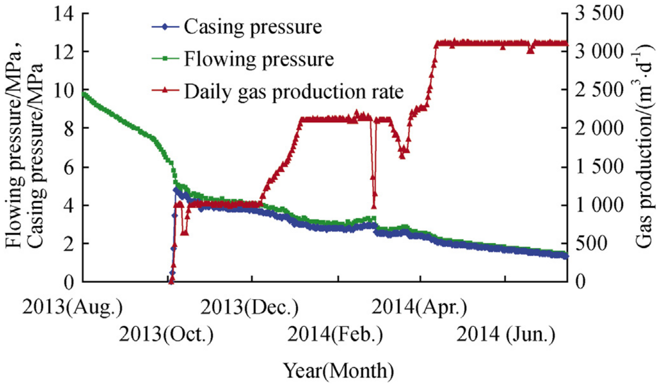

Fig. 3. Drainage and recovery curve of Well 1-44.

reduce the desorption pressure. These two issues must be solved in fracturing design and treatment to the utmost.

At present, fracturing with ultra-low pad in a medium fluid volume followed by quick flowback an hour later has achieved a good effect. "Changing pressure energy into kinetic energy", speeding up the flowback of liquid, reducing water detainment time, meanwhile, quickly releasing the additional pressure on coal seam to make cracks or cleats open easily, may achieve the effect of least water retained in coal seam. Treated with 400 m^3 of fracturing fluid at a flowback rate of 60%, Well 1-44 has a stable daily gas flow rate of above 3000 m^3 at present (Fig. 3).

3.6. Investment benefit should be improved by changing drainage and recovery techniques

The production mechanism of coalbed methane and the stress-strain and dynamic permeability variation pattern of coal reservoirs in the course of recovery should be investigated. Field and lab tests are combined to scientifically quantify the drainage and recovery management and control techniques, and thus to improve drainage and recovery efficiency.

The drainage and recovery process should be changed to improve investment benefit. Rodless drainage and recovery with concentric pipe ejector can solve the eccentric wear of pump rod and tubing once and for all and pump stuck and aneroid phenomena resulted from eccentric wear of pump rod; meanwhile, it can also meet the requirements of drainage and recovery of cluster wells with several high-angle deviated wells on a well pad and horizontal wells; furthermore, when cavity wells are not drilled for horizontal well, large investment can be saved; the horizontal well can be designed as either up dip or down dip, and the well type and well location design can be more diverse.

4. Conclusions

With the constant enlargement of CBM development space, the development of coalbed methane more complicated than that of conventional gas needs the support of high and new technologies, and the demand for the improvement of single well output and technical progress becomes increasingly urgent; adopting dialectical thinking mode can work out proper technologies for the CBM development.

Fund project

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