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Geological controls over coal-bed methane well production in southern Qinshui basin

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Abstract

Southern Qinshui basin is the only area where coal-bed methane (CBM) in anthracitic reservoir is developed in large scale, making the research on development geology an urgent task. The results of tracking geological research on developing engineering of coal-bed methane show that 1) geological structure, tectonic stress field, and coal reservoir pressure control regional changes in productivity; 2) high productivity wells in research area distribute in the secondary anticline core synclinorium while low productivity wells mainly distribute in secondary anticline core of anticlinorium or normal fault zone; 3) primary reservoir pressure has a remarkable effect on coal-bed methane well production; and 4) tectonic stress fields determine development of folds and closure of fractures and control gas content and permeability of coal. The coal reservoir structure is the basic factor affecting productivity of coal-bed methane wells while gas content and permeability are direct geological factors controlling coalbed methane well production. In addition, factors of desorption, diffusion, and seepage network related to reservoir structure determine the development difficulty.

Keywords: geological control; gas production; coal-bed methane well; Qinshui basin

1. Introduction

The coal-bed methane (CBM) development of Southern Qinshui basin is a national demonstration project and Southern Qinshui basin is a base of CBM development. The block studied in the paper is one of the earlier blocks in Southern Qinshui basin. The average gas output per well is basically stable at 1000m^3/d since the wells were put into operation in August, 2006.Some of the wells have been at stable production stage. CBM wells can be classified into 4 types based on productivity of CBM wells, they are stripper wells, strong wells, rising type wells and declining type wells. These 4 types represent producing characters of CBM in stable stages with low production, high production, rising production, decreasing production respectively (Fig.1). As can be seen from Fig.1, there are obvious differences in productivity of CBM wells in regions and cross-wells. Many Chinese researchers have studied productivity of CBM wells in recent years [1-7]. Researchers analyzed the main affecting factors including

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permeability, porosity, adsorption, etc on the production of single well. Most researchers mainly studied influencing factors on the productivity of single well in Qinshui basin at the present. However, CBM development is a whole thing; there is multi well interference effect among the adjacent CBM wells. In the meanwhile, productivity of CBM well is a combined result of geologic control, engineering control (such as drilling, well completion, fracturing), and drainage management. The geologic control is a critical factor which controls productivity of CBM well. Therefore, the research on controlling factors affecting productivity of CBM well is necessary on the whole. This paper discussed geologic controlling factors on the productivity of CBM well in Southern Qinshui basin.

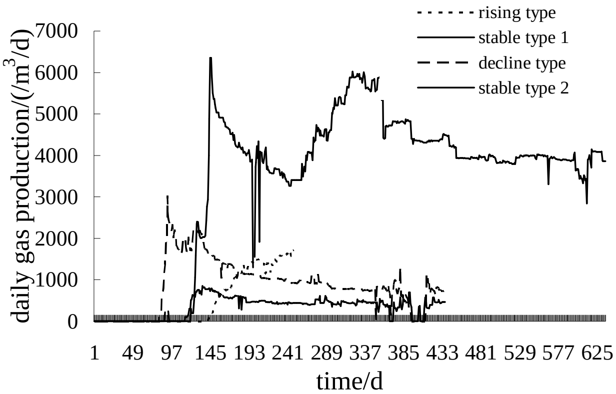


Fig. 1. Production characteristics of CBM well with different productivity (stable type 1 means CBM well has high productivity, stable type 2 means CBM well has low productivity)

2. Geologic controls on regional changes of the productivity of CBM well

The regional changes of productivity of CBM well are related to geologic structure and tectonic stress field in the research area. The structural types are mainly a series of broad and gentle folds with north north-east and nearly north-south direction. The relation between productivity of CBM wells and structure was analyzed (Fig.2), we can see that strong well and the well with moderate productivity distribute mainly in advantageous tectonic location, such as first-degree syncline core, subsidiary anticline core of synclinorium, junction of the structure. The stripper well and drainage well distribute mainly in disadvantageous tectonic location, for example, they might lie in first-degree anticlinal axis, or subsidiary anticlinal axis within anticlinorium, or near the fault zone of the open normal fault.

The stress analysis of subsidiary anticlinal axis where strong well lied is shown in Fig.3.It is clear that there are crushing stresses on neutral flow of synclinorium from figure 3, but there are tensile stresses on neutral flow of subsidiary anticline. The extrusion caused by crushing stress on neutral flow of synclinorium is beneficial to preserve CBM, tensile stress on neutral flow of subsidiary anticline made No 3 coal seam develop fractures, improve coal reservoir permeability, as a result, CBM wells which located in these tectonic location are usually strong wells. There are two secondary synclines on both sides of subsidiary anticline, CBM sealed by hydraulic power during migration, many fractures developed at the top of subsidiary anticline , the location of subsidiary anticline in anticlinorium is bad for preservation of CBM, so the productivity of CBM is lowest. These types of fault developed at research area are normal faults, they are extension faults according to the stress, and provide channels of the migration for CBM dissipation, they aren't beneficial for the preservation of CBM, as a result, CBM wells which located in these tectonic location are usually the stripper wells.

The tectonic stress field is an important affecting factor of controlling permeability. The responding researches [8~10] show that there have ever existed 4 tectonic periods' tectonic stress field at the research area since the coal formed during the Paleozoic. The nearly north-south extrusion during indosinian epoch created many folds with nearly east-west direction and two groups of early shear joints. The north-west and south-east compressional tectonic stress fields exited widely from Yanshan epoch to early Himalayan period [11]. The tectonic compression made Qinshui basin form a north-east syncline as a whole, a series of north- northeast folds and joints with north-west and east-west trend. The north- east folds were formed under tectonic compression overlaying north-west folds formed during Yanshan epoch and early Himalayan epoch. The neotectonic movement from Holocene period,

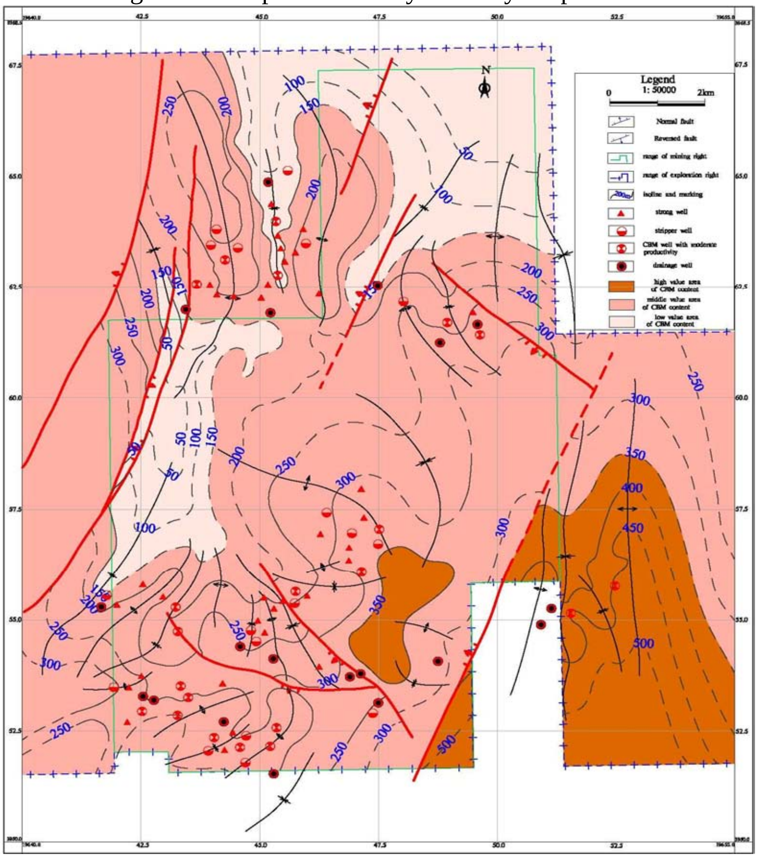


Fig. 2. Relation of structure and productivity

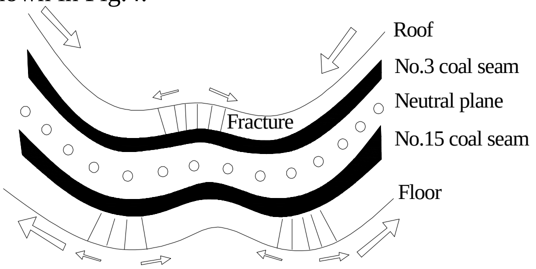
generated nearly north-east and south-west horizontal compressional tectonic stress field, formed some small north-west folds. The north-west joints might be under an extrusion state, the joints and fractures started to close, the coal reservoir permeability became worse, but the nearly northeast joints might be open, they are in favor of the seepage. Therefore, the tectonic stress fields control the enrichment of CBM by the pattern of the folds, at the same time, control the permeability by the open and close of the joints and fractures.

The original coal reservoir pressure is related to gas content, influenced directly the desorption rate of CBM. The strong well of CBM with high initial reservoir pressure actually locates in the areas having high gas content and saturation. The spatial distribution of the reservoir pressure field and the change during the discharge and mining determine desorption rate and the production characteristics of CBM well in the research area. The coal reservoir pressure varies greatly, there are high-pressure reservoir and low-pressure reservoir in the coal seam of Qinshui basin [12], but the coal reservoir pressure is generally low (Table 1). The coal reservoir in Qinshui basin varies ranges from 2~10 MPa [7].

Table 1. statistics of present reservoir pressure in Qinshui Basin

Area	Reservoir pressure (MPa)			Reservoir pressure gradient ($kPa \cdot m^{-1}$)		
	Min value	Max value	Average value	Min value	Max value	Average value
Southern Qinshui Basin	5.1	10.6	7.34	9.35	10.8	9.61

The heights of initial fluid column were calculated based on depth of initial fluid and the altitude of wellhead and the roof of coal seam in order to characterize the relation between the productivity of CBM well and the original coal reservoir pressure. The relation between the height of initial fluid column and the peak of gas production is shown in Fig.4.



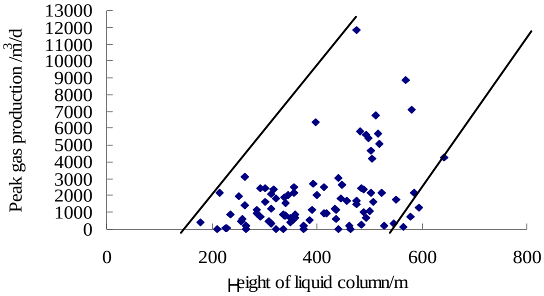


Fig. 3. Stress analysis at different tectonic location in synclinorium Fig. 4. Relationship between peak production and height of liquid column

The peak of gas production is closely related to the coal reservoir pressure as shown in Figure 3, the bigger coal reservoir pressure is, the higher the peak of gas production is. Under the condition of the similar burial history, the reservoir pressure determines gas content and gas saturation of CBM. The higher coal reservoir pressure indicates that the coal reservoir has good gas-bearing properties, in the meanwhile, indicates that the coal reservoir has more energy to drive water and gas from the fractures in the coal to pitshaft. Hence, most CBM wells with high reservoir pressure have also good productivities.

3. Geologic controls on changes of the productivity of adjacent CBM wells

The changes of the productivity of adjacent CBM wells relate to the reservoir structure of high rank coal, the differences of the productivity of adjacent CBM wells lie in the heterogeneity of pores, the cleats and fractures of the coal reservoir. Studies show that the coal reservoir lacks of the mesopores and the exogenic fractures. The exogenic fractures are obviously restricted to the paleotectonic stress field, the density of the cleats in high rank coal is less than medium rank coal, the cleats are filled with calcites and not good for the coal reservoir penetrability.

The coal rocks developed the microscopic fracture, shrinkage fracture, static fracture and structural fracture are common in the coal rocks (Fig.5) , the density of the microscopic fracture is much higher than it in the cleats, the microscopic fractures are not restricted to the coal maceral composition and filled with the minerals. The super microscopic fractures developed in the coal because of molecular directional realignment, which was caused by thermal evolution of high rank coal, had a significant improvement in the coal reservoir penetrability. It is clear that the lack of mesopores makes the time (which CBM diffuses from the micropore to the macropore and then seeps or migrates directly to the exogenic fracture and the cleat) too long. The spread and extension of pressure drop are quick in the exogenic fracture, followed by the microscopic fracture and the macropore, lowest in the micropore. As a result, pressure of CBM well in the location which the exogenic fracture developed very well first drops, the productivity rises to a higher value in a relatively shorter time .for example, CBM well located in subsidiary anticline of synclinorium are often like that (Figure 2).

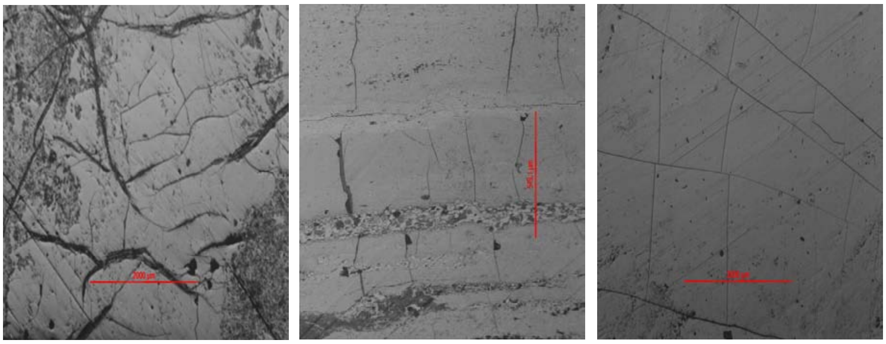


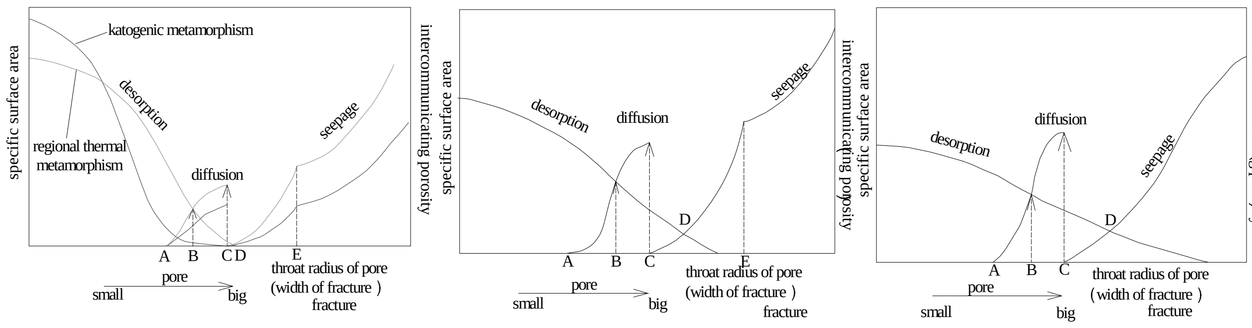
Fig. 5. Microscopic fracture development characteristics of high rank coal in research area

Compared medium rank coal and low rank ones, productivity of CBM wells in block of coal matrix and the fractured zones with good connectivity; the latter is clearly higher than the former in high rank coal. It is because of the development degree of exogenic fracture and differences of well testing permeability. In the meanwhile, exogenic fracture is the main contributor of well testing permeability, the development degree of exogenic fracture is low, the connectivity of coal reservoir is poor, which lead to lower permeability of coal reservoir and lower productivity of CBM wells.

4. Productivity's geologic controlling mechanism of CBM well

The productivity of CBM well depends on coal-bed gas content and coal reservoir permeability. Enough coal-bed gas content in coal reservoir is the material base of gas producing, coal reservoir permeability which depends on development degree of pore and fracture system determines the flow conductivity of CBM, The congruent relationship between productivity of CBM well and coal-bed gas content is discovered according to analysis on the distribution of CBM gas content and productivity characteristic of CBM well, the productivity of CBM well is relatively high in the area with high coal-bed gas content, but there is no obvious congruent relationship between productivity of CBM well and the coal-bed gas content in stable producing stage. The analysis also shows that not all strong wells distribute the area with high coal-bed gas content, stripper wells lie in the area with low coal-bed gas content. According to contrast and analysis, it mainly results from two factors, one is the pore and fracture system of coal reservoir, the other is difference of depressurizing speed of coal reservoir because of the difference of drainage and pressure lowering. The differences of contraction of coal matrix bring out the difference of connectivity of the pore and the fracture system of coal reservoir, the underspeed of desorption, diffusion, seepage structural network and connectivity controlled by the pore and the fracture system is different.

Compared with high rank coal by the katogenic metamorphism, desorption, diffusion, seepage structural network, and the action relation are important to the output of CBM. The process continuity is the key to the stable production and high production. Fig.6 is the pattern relation diagram of desorption, diffusion, seepage structural network, and action relation of different rank coals. Anthracitic porosity formed by katogenic metamorphism is very low, coal cleat develops badly [13], desorption, diffusion, seepage structural network, and action relation of anthracite by regional metamorphism are better. The interconnected pore and cleat (which is filled with calcite) develop badly, which lead to the time (which the pressure drops from the pitshaft to the coal seam) lasts too long, the route from filling pore to fracture becomes far, the time for desorption becomes longer. The desorption ability of coal reservoir is relatively low, the diffusion of CBM is mainly transitional diffusion, the seepage happens mainly in exogenous fracture. CBM diffuses from the micropore and minipore to the exogenous fracture difficultly, the time which seepage of CBM happened in the exogenous fracture is relatively late.



(a) High rank coal (b) Medium rank coal (c) Low rank coal

Fig. 6. Desorption, diffusion and seepage structural network and relation model of different rank coal

From analysis above, the production potential of high rank coal in research area is much higher, and its unique reservoir structure is a prerequisite for higher productivity. And reservoir structural character of high rank coal determines desorption, diffusion and seepage network ones of CBM, so that its development is difficult. Therefore, reservoir of high rank coal needs definite engineering measures to improve its flow conductivity to obtain higher productivity.

Based on the analysis of geological factors and control mechanism on productivity of CBM well, this paper acquires the following conclusions:

(1) Geological structure, tectonic stress field and coal reservoir pressure control regional changes of productivity. Strong well distributes in secondary anticline core of synclinorium, and low productivity mainly distributes in secondary anticline core of anticlinorium or fault zone of extension fault in research area. Primary reservoir pressure has remarkable effect on CBM well production. The four-period tectonic stress fields determine development of folds and development and closure of fractures, and control gas content and permeability of coal.

(2) The reservoir structure of coal is a basic reason for productivity changes of CBM wells.

(3) The productivity of CBM well depends on gas content and permeability of coal reservoir, and desorption, diffusion and seepage network characteristics under reservoir structure controlling determines its development difficulty.

Acknowledgements

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