An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)
©2014 China University of Mining and Technology Press, Xuzhou, ISBN 978-7-5646-2437-8

Control Actions of Hydrodynamic Conditions of Groundwater to Gas Productions of Coal Bed Methane Straight Wells in Fanzhuang Block

Shiqi Liu[1],Shuxun Sang[2],Qipeng Zhu[2]
1 China University of Mining and Technology,liushiqi19840920@163.com
2 *China University of Mining and Technology/Key Laboratory of CBM Resources and Reservoir Strata Process (CUMT),State Ministry of Education,shuxunsang@163.com*

Abstract This study analyzed the control actions of hydrodynamic conditions of groundwater to gas productions of coal bed methane (CBM) straight wells on the basis of production data and geological data of CBM wells in Fanzhuang Block and hydrogeological characteristics in southern Qinshui basin. Then mechanisms of the control actions were discussed. The results show that groundwater fluid potential in Fanzhuang Block has positive correlation relationships with gas productions of CBM wells in research area. Groundwater fluid potential influences gas productions of CBM wells through drainage and depressurization effects. Coal bed reservoir with high groundwater fluid potential usually has low water content and small water recharging,which is beneficial to the decrease of coal bed pressure and migration and output of CBM. In this condition, CBM wells usually have high daily gas productions. Within a relative large region,the control actions of hydrodynamic conditions of groundwater to gas productions of CBM wells are weak. But the control actions are strong in a relatively small region because of the stronger seepage capability of groundwater. The control actions of hydrodynamic conditions of groundwater to gas productions of CBM wells become weak when groundwater fluid potential is higher than 700 m above sea level,because of the low water content and small water recharging of coal bed reservoir.
Keywords groundwater fluid potential, gas production, coal bed methane well, Fanzhaung block

Introduction

The development of in-situ CBM surface well is the promotion process of desorption, diffusion, seepage and output of CBM through development engineering,on the basis of coal-rock mass with rich gas (Liu et al. 2012b, Liu 2013, Liu et al. 2013, Sang et al. 2009). The research on coal-rock mass with rich gas,which is development geology theory of CBM,has greatly enhanced the CBM industrial of China and improved gas production of single well (Liu et al. 2012b, Liu 2013, Liu et al. 2013, Sang et al. 2009). Coal-rock mass with rich gas has two essential characteristics,which are gas content and permeability (Liu et al. 2012b, Liu 2013, Liu et al. 2013, Sang et al. 2009). Gas content is the material guarantee of CBM development (Liu et al. 2012b, Liu 2013, Liu et al. 2013, Sang et al. 2009). Permeability is the physical basis of CBM output (Liu et al. 2012b, Liu 2013, Liu et al. 2013, Sang et al. 2009). Gas content and permeability are the core contents of the research on development geology theory of CBM and are mainly influenced by coal structure,burial depth,coal body structure,sealing capacity of roof and floor plate and so on (Fu et al. 2009, Groshong Jr et al. 2009, Han et al. 2009, Liu et al. 2012a, Liu 2013, Sang et al. 2005, Wang et al. 2006, Zhang et al. 2011). The research on development geology theory of CBM gives less concern on hydrogeological conditions. The research on hydrogeological conditions is generally limited to the control of gas content such as the hydraulic sealing,the hydraulic plugging and the hydraulic migration of CBM caused by hydrogeological conditions during the gas accumulation process (Chi 1998, Fu et al. 2001, Tang et al. 2003, Wang et al. 2001, Wang et al. 2006). With the deepening of understanding,more scholars realize that control actions of high gas content and high permeability to the deliverability of CBM wells have certain Limitations. Hydrogeological characteristics have important control actions to CBM development. During the research on development geology of CBM,gas content-based and permeability-based division plan of development units is often hard to get satisfactory gas production. However,with the consideration of hydrogeological conditions,division plan of development units can greatly improve efficiency and success rate of well location. This study analyzed the control actions and mechanisms of hydrodynamic conditions of groundwater to gas productions of CBM wells on the basis of production data and geological data of CBM wells in Fanzhuang Block and hydrogeological characteristics in southern Qinshui basin,thus serving development of CBM wells in this area.

Background

Background of Qinshui Basin

Qinshui Basin is located in the southeast of Shanxi,China (fig. 1) with a coal area of 29500 km^2 and 5.1×10^{11} t of coal reserves (Liu 2013, Liu et al. 2012a). It is a main super-huge type coal-bearing basin in China as well as one of the largest CBM fields with high rank coal in the world (Liu 2013, Liu et al. 2012a).

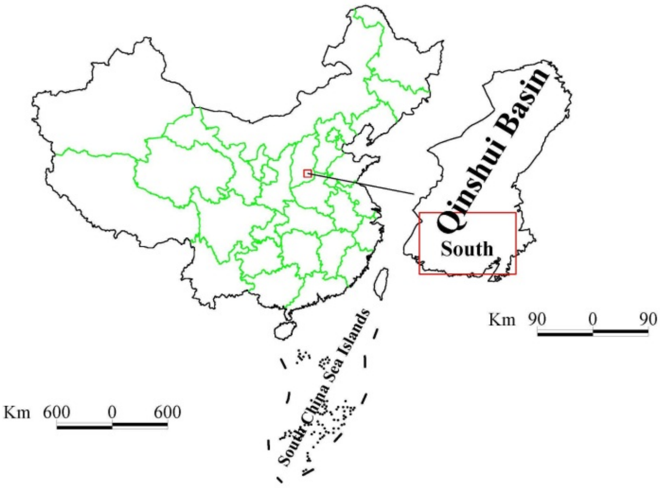

Fig. 1 *Geographical location of Qinshui Basin*

Taiyuan and Shanxi formations are the main coal-bearing strata in southern Qinshui Basin which belong to the Permo-Carboniferous system (Liu 2013, Liu et al. 2012a,b). Shanxi formation developed in deltaic deposit on the background of epicontinental sedimentation. The thickness of Shanxi formation is 45 to 86 m; coal-bearing strata are mainly fine sandstone,aleurolite and mudstone (Liu 2013,Liu et al.2012a,b).The degree of metamorphism of coal in southern Qinshui Basin is high and belongs to No.3 stage of anthracite (Liu 2013, Liu et al. 2012a,b). It is a typical CBM reservoir of high rank coal as well as the main region where China realizes commercial development of CBM (Liu 2013, Liu et al. 2012a,b). Shanxi Formation in southern Qinshui Basin has four coal beds,respectively numbered as 1#~4# from top to bottom (Liu 2013, Liu et al. 2012a,b). 3# coal bed is the most stable coal bed with the maximum thickness of single layer between 5.30 and 8.60m distributed in the whole area (Liu 2013, Liu et al. 2012a,b). It is the main target coal bed of exploration and development of CBM as well as the target coal bed of the research in this paper.

Coal-bearing strata in southern Qinshui Basin has typically experienced four structural evolution periods which are Hercynian period,Indosinian period,Yanshanian period and Himalyan orogenic period (Liu 2013, Lv et al. 2012, Meng et al. 2011, Shen et al. 2010). The present tectonic framework of coal-bearing strata is formed by continued decrease of buried depth and structural differentiation in Himalyan orogenic period (Liu 2013, Lv et al. 2012, Meng et al. 2011, Shen et al. 2010). The coal-bearing strata also experienced settlement and increasement of buried depth during Hercynian-Indosinian period,equalization and fluctuation during Indosinian period and early Yanshanian period,and tectonic uplift in middle and late Yanshanian period (Liu 2013, Lv et al. 2012, Meng et al. 2011, Shen et al. 2010). Shanxi and Taiyuan formations in southern Qinshui Basin lack of hydraulic connection because of the aquifuge on the top of Shanxi formation which consists of mudstone and sandy shale (Han et al. 2010, Liu 2013, Liu et al. 2012b, Sang et al. 2009, Zou et al. 2010). Roof sandstones during top main seams are the major aquifers of Shanxi formation (Han et al. 2010, Liu 2013, Liu et al. 2012b, Sang et al. 2009, Zou et al. 2010). Water equipotential surface declines from the north to the south and reduces to the lowest at southeast. Groundwater recharging mainly comes from northwest (Han et al. 2010, Liu 2013, Liu et al. 2012b, Sang et al. 2009, Zou et al. 2010). Hydrodynamic conditions are complex in the area with several relative “low-lying” catchment centers (Han et al. 2010, Liu 2013, Liu et al. 2012b, Sang et al. 2009, Zou et al. 2010).

Background of Fanzhuang Block

The major structural configuration (fault strike and fold axis direction) of 3# coal bed in Fanzhuang Block is NNE direction (fig.2). The secondary fold is developed with various directions. Characteristics of the secondary fold show the influences of multiple tectonism. Fault is not developed in Fanzhuang Block (fig.2). The groundwater fluid potential in Fanzhuang Block is typical stagnant type with “low-lying” water equipotential surface (fig. 3). Water equipotential surface mainly declines from the north to the south and reduces to the lowest at southeast (fig.3). Groundwater recharging mainly comes from northwest. Hydrodynamic conditions are complex in the area with several relative “low-lying” catchment centers (fig.3). Hydrodynamic conditions of groundwater in Fanzhuang Block are the same as the whole southern Qinshui basin.

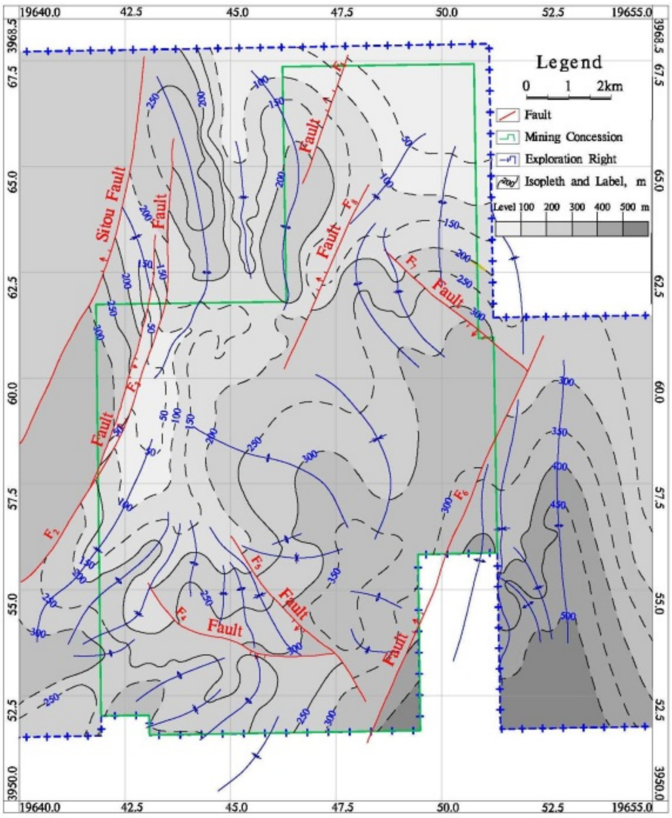

Fig. 2 Areal structure of No.3 Coal Bed in Fanzhuang Block

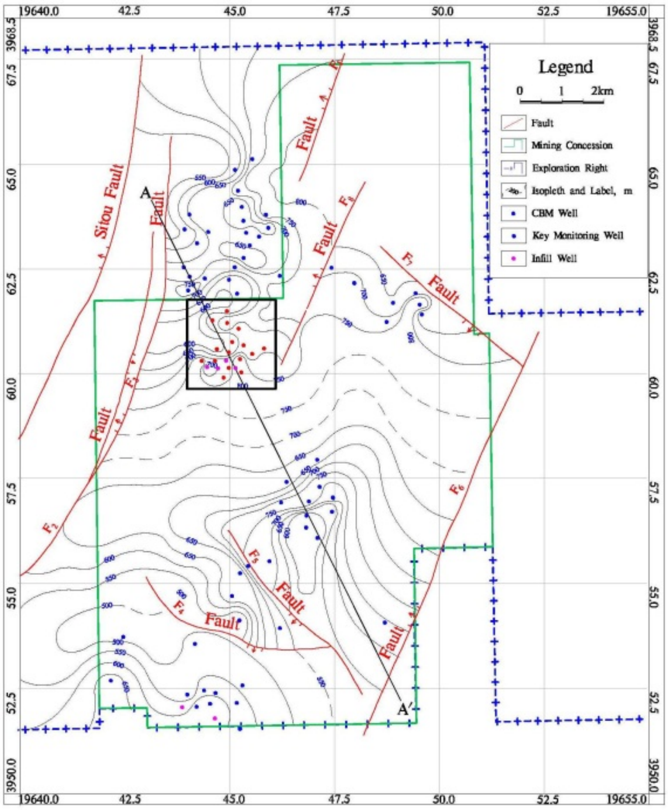

Fig. 3 *Groundwater fluid potential in Fanzhuang Block*

Control actions of groundwater fluid potential to gas productions of CBM wells

Influences of groundwater fluid potential to gas productions of CBM wells

The influences of groundwater fluid potential to gas productions of CBM wells can be divided into two phases (fig.4). The first phase,groundwater fluid potential is lower than 700 m above sea level. In the phase,with the growing of groundwater fluid potential,average daily gas production increases rapidly and reaches the maximum value at 700 m above sea level (fig.4). The second phase,groundwater fluid potential is higher than 700 m above sea level. In this phase,with the growing of groundwater fluid potential,average daily gas production has a small increase and generally less than the average daily gas productions when groundwater fluid potential is lower than 700 m above sea level (fig.4). The average daily gas productions of 16 key monitoring CBM wells have obvious positive correlation relationship with groundwater fluid potential (fig.5). Average daily gas production grows with the increase of groundwater fluid potential. In conclusion,groundwater fluid potential has some influences to gas productions of CBM wells and the influences get wake when groundwater fluid potential reaching a certain degree. Fig. 5 and fig. 6 also show that to the whole Fanzhuang Block,the influences of groundwater fluid potential to gas productions of CBM wells are relatively wake. But,to some small region,especially to the region with serried CBM wells,the influences are relatively strong and adjacent CBM wells have different gas production characteristics.

Take Profile AA’ as example (fig. 3 and fig. 6),gas productions of CBM wells in the profile doesn’t have obvious relationship with groundwater fluid potential. NO.5 CBM well has the highest groundwater fluid potential with low average daily gas production which is 483.7

m/d^3 (fig.6). NO.1 and NO.2 CBM well locate in the "source" of groundwater fluid potential,whose groundwater fluid potential is comparable to NO.5 CBM well (fig. 6). But,the average daily gas productions of NO.1 and NO.2 CBM wells are much higher than NO.5 CBM well,because of gas content and permeability. NO.3 CBM well also locates in the "source" of groundwater fluid potential. This "source" overall locates between two catchment centers with a lower groundwater fluid potential comparing with NO.5 and NO.2 CBM wells. NO.3 CBM well has low permeability because of its tectonic position which is core of secondary syncline belonging to an anticlinorium and its burial depth which is more than 700 m. Along with these factors,NO.3 CBM well has low gas production. Groundwater fluid potential has strong influences to adjacent CBM wells. For example,NO.5 and NO.6 CBM wells have relatively high groundwater fluid potential and large gas productions. Their adjacent CBM wells which respectively are NO.4 and NO.7 CBM wells locate in the catchment centers of groundwater fluid potential and have low gas productions. NO.4 CBM well is adjacent to NO.3 and NO.5 CBM wells and locates in the catchment center between NO.3 and NO.5 CBM wells. The gas production of NO.4 CBM well is much smaller than NO.3 and NO.5 CBM wells.

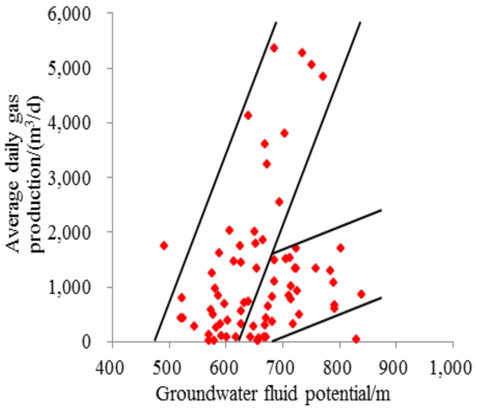

Fig.4 *Relationship between groundwater fluid potential and daily gas productions of CBM wells in Fanzhuang Block*

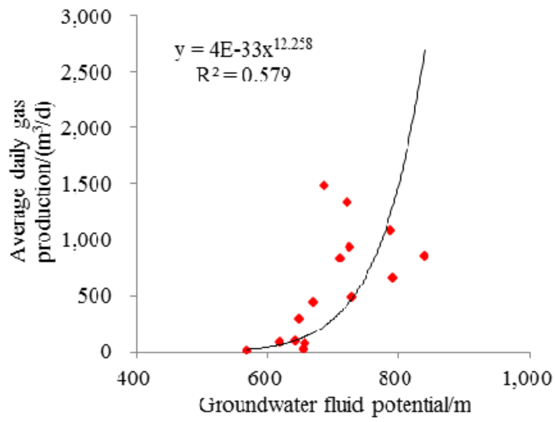

Fig.5 *Relationship between groundwater fluid potential and daily gas productions of key monitoring CBM wells*

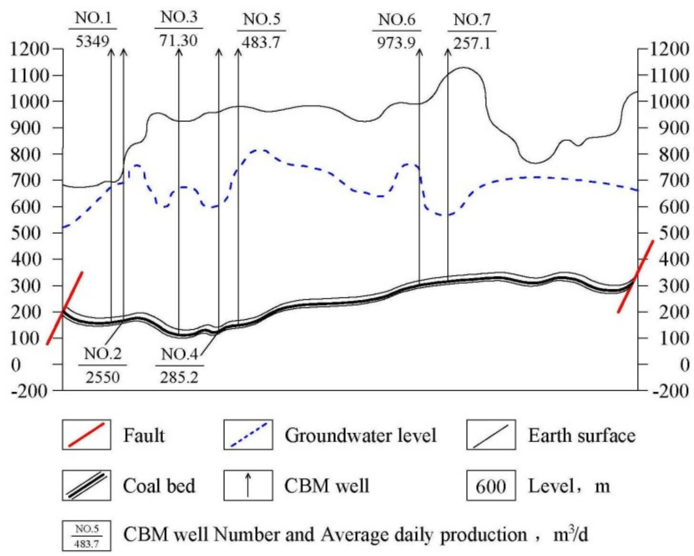

Fig. 6 *Groundwater fluid potential and daily gas productions of CBM wells in Profile AA'*

Control mechanisms of groundwater fluid potential to gas productions of CBM wells

Average daily gas productions of CBM wells in Fanzhuang block have obvious negative correlation with average daily water productions (fig.7). CBM wells with low water productions usually have high gas productions. Average daily water productions of CBM wells have obvious negative correlation with groundwater fluid potential (fig.8). This means that CBM wells with low groundwater fluid potential usually have large water recharging which increases the difficulty of drainage and depressurization effects.

Without cross-flow supplement,control actions of groundwater fluid potential to gas productions of CBM wells are mainly shown in two aspects. The first aspect,groundwater fluid potential controls the flow direction of coal bed water. CBM wells with low groundwater fluid potential locate in the "low-lying" catchment centers and have relatively large water recharging. CBM wells with high groundwater fluid potential locate in the "prominent" source and have relatively small water recharging. Coal bed water flows from the area with high groundwater fluid potential to the area with low groundwater fluid potential. The second aspect,groundwater fluid potential controls the water content of coal bed reservoir. The area with low groundwater fluid potential usually has high water content that guarantees relatively large coal bed water flowing to the CBM well. The area with high groundwater fluid potential usually has low water content that water recharging is small. Therefore,CBM wells with low groundwater fluid potential usually have high daily water productions because of large water recharging. The large water recharging and high water content also prevent the decrease of coal bed pressure. CBM wells with high groundwater fluid potential usually have low daily water productions because of small water recharging. The small water recharging and low water content are beneficial to the decrease of coal bed pressure. In conclusion,groundwater fluid potential influences gas productions of CBM wells mainly through drainage and depressurization effects. Great drainage and depressurization effects are beneficial to desorption and migration of CBM and increase of daily gas production of CBM wells.

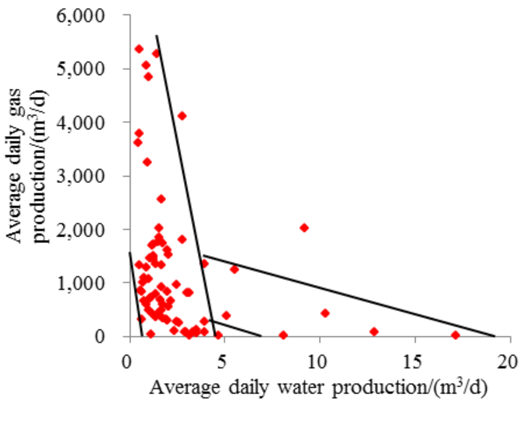

Fig. 7 *Relationship between average daily gas productions and average daily water productions of CBM wells in Fanzhuang Block*

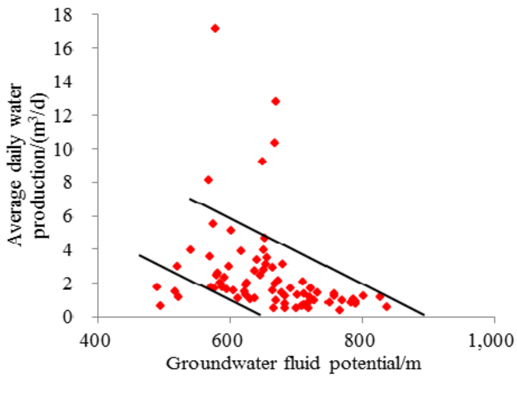

Fig. 8 *Relationship between average daily water productions and groundwater fluid potential of CBM wells in Fanzhuang Block*

Control actions of drainage and depressurization effects to gas productions of CBM wells are also mainly shown in two aspects. The first aspect,in drainage stage,great descend range of coal bed pressure is beneficial to desorption of CBM and causes large gas recharging of CBM wells. Small descend range of coal bed pressure causes small desorption volume of CBM and small gas recharging of CBM wells. The second aspect,Large desorption volume of CBM is beneficial to the increase of gas saturation and gas relative permeability in coal bed. The increase of gas saturation and gas relative permeability are conducive to the migration of CBM and impedes the seepage of coal bed water. Small desorption volume of CBM is conducive to the increase of water saturation and water relative permeability in coal bed. The increase of water saturation and water relative permeability are conducive to the seepage of coal bed water and impedes the migration of CBM.

As mentioned earlier,the area with low groundwater fluid potential usually has large water recharging outside the well control range and high water saturation inside the well control range,which prevents the decrease of coal bed pressure. In this case, area whose pressure has decreased to critical desorption pressure and desorption volume of CBM are both small. Coal bed fractures give priority to water seepage. Large water saturation and water relative permeability and small gas relative permeability impede the migration of CBM. In production-gas stage, low desorption volume of CBM and high water relative permeability prevent the increase of gas production of CBM wells and promote high water production.

The area with high groundwater fluid potential usually has small water recharging outside the well control range and low water saturation inside the well control range after the drainage of coal bed water,which is conducive to the decrease of coal bed pressure. In this case,area whose pressure has decreased to critical desorption pressure and desorption volume of CBM are both large. With the increase of desorption volume of CBM,gas saturation grows fast as well as water saturation drop rapidly. Large gas saturation and gas relative permeability and small water relative permeability are conducive to the seepage of CBM and impede the seepage of water. Coal bed fractures give priority to gas seepage. In production-gas stage,high desorption volume of CBM and high gas relative permeability increase gas production of CBM wells and debase water production.

Hydrodynamic conditions of groundwater in Fanzhuang Block are complex. Different areas have different hydrodynamic conditions. Therefore,in different areas,hydrodynamic conditions have different influences to the deliverability of CBM wells. The groundwater fluid potential in Fanzhuang Block is typical stagnant type that groundwater has weak liquidity in a large range. But,the liquidity of water is strong in a small range. As a result,the influences of groundwater fluid potential to the gas productions of CBM wells are relatively wake in a large range and are relatively strong in a small range. Water recharging and water saturation of coal bed reservoir has decreased to a low level in the area with high groundwater fluid potential,which causes weak influences to the gas productions of CBM wells.

In addition, without cross-flow supplement,with the production of CBM wells,coal bed pressure of areas with high groundwater fluid potential likely further decrease. In this case,desorption volume of CBM and gas productions of CBM wells will increase.

Conclusions

This study analyzed the control actions and mechanisms of hydrodynamic conditions of groundwater to gas productions of CBM straight wells and got the following conclusions.

Groundwater fluid potential in Fanzhuang Block has positive correlation relationships with gas productions of CBM wells. The control actions of hydrodynamic conditions of groundwater to the gas productions of CBM wells is weak in a large range,but strong between adjacent CBM wells. The control actions become weak when groundwater fluid potential is higher than 700 m.

Groundwater fluid potential influences gas productions of CBM wells through drainage and depressurization effects. The liquidity of coal bed water is weak in a large range,But strong in a small range. In the area with a certain high groundwater fluid potential,influences to gas productions of CBM wells decrease. Coal bed reservoir with high groundwater fluid potential has low water content and small water recharging,which is beneficial to the decrease of coal bed pressure and migration and output of CBM. In this condition,CBM wells usually have high gas production.

Acknowledgments

We thank Mengxi Li and Lilong Wang from the Shanxi CBM Branch of Huabei Oilfield Company for their assistances. This study was supported by the National Natural Science Foundation of China (No.41330638,41272154,51325403,51104148 and 51204162),the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD),a China Postdoctoral Science Foundation funded project (No.2014M551705) and Jiangsu Planned Projects for Postdoctoral Research Funds (No.1302049B).

References

Chi WG (1998) Hydrogeologic controlled actions of coal bed gas in Qinshui Basin. Petroleum Exploration and Development 25(3): 15-18

Fu XH, Qin Y, Wang GGX, Rudolph V (2009) Evaluation of coal structure and permeability with the aid of geophysical logging technology. Fuel 88(11): 2278-2285

Fu XH, Qin Y, Wang WF, Jiao SH (2001) Hydrogeologic controlled properties of coal bed gas in central-southern Qinshui Basin. Coal Geology of China 13(1): 31-34

Groshong Jr RH, Pashin JC, McIntyre MR (2009) Structural controls on fractured coal reservoirs in the southern Appalachian Black Warrior foreland basin. Journal of Structural Geology 31(9): 874-886

Han FS, Busch A, Van Wageningen N, Yang JL, Liu ZY, Krooss BM (2010) Experimental study of gas and water transport processes in the inter-cleat (matrix) system of coal: Anthracite from Qinshui Basin,China. International Journal of Coal Geology 81(2): 128-138

Han JZ, Sang SX,Cheng ZZ, Huang HZ (2009) Exploitation technology of pressure relief coalbed methane in vertical surface wells in the Huainan coal mining area. Mining Science and Technology (China) 19(1): 25-30

Liu HH, Sang SX, Wang GGX, Li YM, Li MX, Liu SQ (2012a) Evaluation of the synergetic gas-enrichment and higher-permeability regions for coalbed methane recovery with a fuzzy model. Energy 39(1): 426-439

Liu SQ (2013) Geology and engineering cooperative control and prediction for the deliverability of CBM straight wells in southern Qinshui Basin. Xuzhou: China University of Mining and TechnologySchool of Mineral Resource and Earth Science

Liu SQ, Sang SX, Li MX, Liu HH, Huang HZ, Zhang JF, Xu HJ (2013) Key geologic factors and control mechanisms of water production and gas production divergences between CBM wells in Fanzhuang block. Journal of China Coal Society 38(2): 277-283

Liu SQ, Sang SX, Li MX, Liu HH, Wang LL (2012b) Control factors of coalbed methane well depressurization cone under drainage well network in Southern Qinshui Basin. Journal of China University of Mining and Technology 41(6): 943-950

Lv YM, Tang DZ, Xu H, Luo HH (2012) Production characteristics and the key factors in high-rank coalbed methane fields: A case study on the Fanzhuang Block,Southern Qinshui Basin,China. International Journal of Coal Geology 96-97(0): 93-108

Meng ZP, Zhang JC, Wang R (2011) In-situ stress,pore pressure and stress-dependent permeability in the Southern Qinshui Basin. International Journal of Rock Mechanics and Mining Sciences 48(1): 122-131

Sang SX, Liu HH, Li YM, Li MX, Li L (2009) Geological controls over coal-bed methane well production in southern Qinshui basin. Procedia Earth and Planetary Science 1(1): 917-922

Sang SX, Zhu YM, Zhang J, Zhang XD, Tang JX (2005) Solid-gas interaction mechanism of coal-adsorbed gas (Ⅱ)-coal pore structure and solid-gas interaction. Natural Gas Technology 25(1): 13-16

Wang MS, Tang DZ, Wei YP, Xu WJ, Leng X (2006) Reservoir characteristics and enrichment mechanism of the coal-bed gas in the north of Qinshui Basin. Petroleum Geology and Experiment 28(5): 440-444

Shen J, Qin Y, Fu XH, Wang BW, Yang S, Zhao LJ (2010) Application of structural curvature of coalbed floor on CBM development in the Zaoyuan block of the southern Qinshui Basin. Mining Science and Technology (China) 20(6): 886-890

Tang SH, Ma CX, Yuan HZ (2003) Hydrogeological conditions of Carboniferous-Permian coal reservoir in north China. Natural Gas Industry 23(1): 32-35

Wang HY, Zhang JB, Liu HL, Qin Y (2001) Hydrogeologic feature of coalbed methane reservoir in the southern Qinshui Basin. Coal Geology and Exploration 29(5): 33-36
Zhang XD,Liu YH, Sang SX, Liu H (2011) Study of the gas diffusion mechanism in high-rank coal reservoirs. Journal of China University of Mining andTechnology 40(1): 43-48
Zou MJ, Wei CT, Pan HY,S esay KS, Cao J (2010) Productivity of coalbed methane wells in southern of Qinshui Basin. Mining Science and Technology (China) 20(5): 765-769, 777