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A quantitative model using geophysics logging data to predict gas production in coalbed methane wells: a case study in Shizhuangnan Block, northern China

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Summary

Gas production in coalbed methane (CBM) wells is a variable controlled by many factors, which is difficult to be predicted. An additional complexity is added if only conventional logging data is provided. In this article, new methods to evaluate two indexes (coal texture index and water bearing index) are developed using caliper, spontaneous potential and resistivity curves. Then, five important factors which are highly related to gas production are put forward, covering storage condition and hydrogeological condition. Based on these five factors, a quantitative prediction model is established. Applying to a total of 97 CBM wells, results indicate this method is effective, with an accuracy of 79%. This method can be used as a helpful tool in CBM investment and development. It can also be used to evaluate the reservoir parameters for newly discovered reservoirs, including coal texture, initial water-in-place and gas production. With these, CBM wells can be better evaluated and production costs can be saved a lot.

Introduction

The Qinshui basin is the largest coalbed methane producing area and a typical high-rank coal field in China, with an area of 23.5×10^3 km². It evolved from Late Paleozoic to the end of the Mesozoic. Coals in the Qinshui basin are anthracite with a vitrinite reflectance of 2.2%-4.5% because of a tectonic-thermal event during the Jurassic to Cretaceous Yanshannian Orogeny (Su et al., 2005). Shizhuangnan (SZN) block is located in the southern part of Qinshui basin and the east wing of Qinshui synclinorium. Geological structures in this block are relatively simple.

Strata in the study area consists of the Cambrian, Ordoviclian, Pennsylvanian Benxi (C_2b) and Taiyuan (C_3t), Permian Shanxi(P_1s), Xiashihezi (P_1x), Shangshihezi(P_2s), Shiqianfeng (P_2sh) and Triassic Liujiagou Formation (T_1l), as well as Quaternary deposits (Zhang et al., 2016). The No.15 coal seam of the Taiyuan formation and No.3 coal seam of the Shanxi Formation in the Pennsylvanian– lower Permian System are the most continuous and stable coal seams. And the No.3 coal seam is currently the target seam of CBM development in Shizhuangnan Block and also the study seam in this article. The burial depth ranges from 450 to 1000 m, the majority centering on 500-700m. In this study area, only conventional logging data including the spontaneous potential (SP) curve, the gamma ray (GR) curve, the density (DEN) curve, the caliper (CAL) curve, as well as the deep resistivity (RD) and shallow resistivity (RS) curves in CBM producing wells and some production data are provided for research.

This paper provides a quantitative method to predict gas production in CBM wells. First, five important factors for prediction are put forward by analysing the logging data and production data of 44 CBM wells. Then, the prediction model is established based on these five indexes. To verify this model, a total of 97 CBM wells are tested by this method, getting an accuracy of 79%.

Quality factor of coal seam (Q_{cs})

Comparing with conventional reservoirs, logging responses in coal reservoirs are obvious and typical, showing low GR, low DEN, low SP, high RD and high CAL. In SZN block, the daily average gas production (DAP) ranges from 0 to 2500 m³. According to the drainage and mining testing data in this block, we divide the wells into three levels, high-yield wells (DAP greater than 1000m³/d), middle-yield wells (DAP lies between 300 and 1000 m³/d) and low-yield wells (DAP less than 300 m³/d), in this way, high- and middle-yield (HM) wells means those in which the DAP is greater than 300 m³/d.

1. Coal texture index (ICT)

As a result of the tectonic activities during the process of hydrocarbon migration and accumulation, coal texture types can be classified as undeformed, cataclastic, granulated and mylonitized with an increasing degree of deformation (Xue et al., 2012). In SZN block, results from the core description of the 168 coal cores show that coal textures of the No. 3 coal seam are mainly undeformed and cataclastic, a small part of them are granulated, and none of them are mylonitized.

Some scholars have discussed the logging response of coal texture. As far, there was no accurate identification method of coal textures. Logging response values have an increasing or decreasing trend with the increasing degree of deformation from undeformed to granulated coals. In this article, according to the study, the values of CAL have an increasing trend. And moreover, the values of CAL have a relatively high correlation with the degree of deformation, while other values including DEN, GR and RD overlap among different coal texture types. The coal seam of well TS7 includes 9 core samples from bottom to top, as shown in Fig. 1.
From this, the coal texture index (ICT) is defined as,

$$ICT=CAL/23.8 \quad (1)$$

where CAL is the value of CAL curve. If this index ICT<1, it can be identified as undeformed coal, if not, it is identifies as cataclastic or granulated coal.

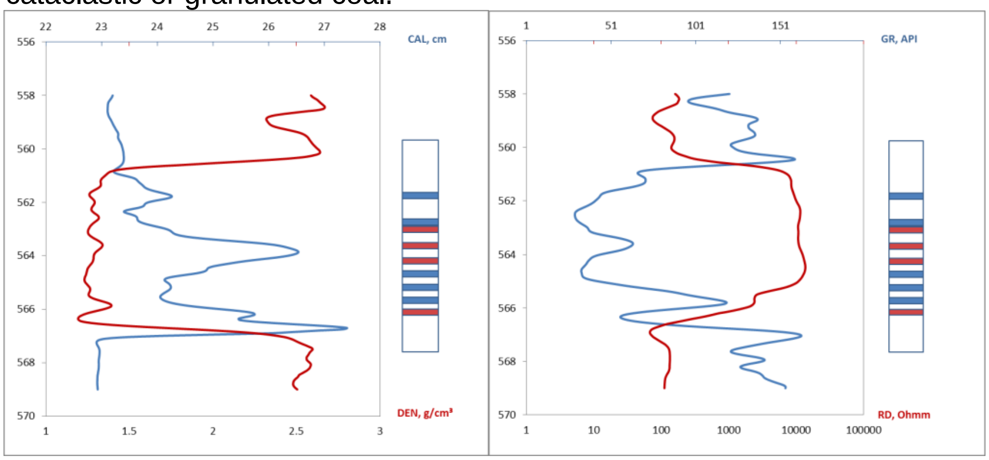

Figure 1 *the logging response of CAL (left, blue curve), DEN (left, red curve), GR (right, blue curve) and RD (right, red curve) among undeformed (blue stripes) and cataclastic (red stripes) coals*

2. Water bearing index (IWB)

As we known, the No. 3 coal seam is within the anthracite rank. Pure coal has a high resistivity, which can be equivalent to the skeleton of argillaceous rock, and the ash can be equivalent to the mud component. Thus, Archie's formulas should be suitable to the coal seam. Archie defined the formation factor F as the ratio of formation 100% saturated with water R_0 to the formation water resistivity R_w,

$$F = R_0/ R_w \quad (2)$$

The relationship between formation factor and porosity is shown as,

$$F = a/ \varphi^m \quad (3)$$

where φ refers to porosity, m means porosity exponent, and a means lithology index.

Based on equation 2 and 3, we can get

$$R_0/R_w = a/\varphi^m \quad (4)$$

In coal seam, R_0 is difficult to get as gas accumulates in the formation. According to Archie's experiment, we can get another equation,

$$R_t/R_0=1/S_w^2 \quad (5)$$

where R_t refers to actual formation resistivity, here we can use RD to replace R_t.

Combining equation 4 and 5, we can get

$$S_w^2 \varphi^m = R_w / R_t \tag{6}$$

then

$$IWB = R_w / R_t = S_w^2 \varphi^m = (S_w \varphi)^2 = (\varphi_w)^2 \tag{7}$$

where φ_w refers to water porosity, defined as $S_w\varphi$. Among the pores of coal seam, if the water porosity is high, then the remaining gas content is small. So we define this *IWB* as the index of water bearing, which can be calculated by the ratio of R_w/R_t. And R_w can be obtained based on the relationship with static spontaneous potential (SSP).

To verify our study, the relationship between daily average water production and IWB of 44 CBM wells is shown in Fig. 2. It shows that this index have a relatively high correlation with actual water production performance.

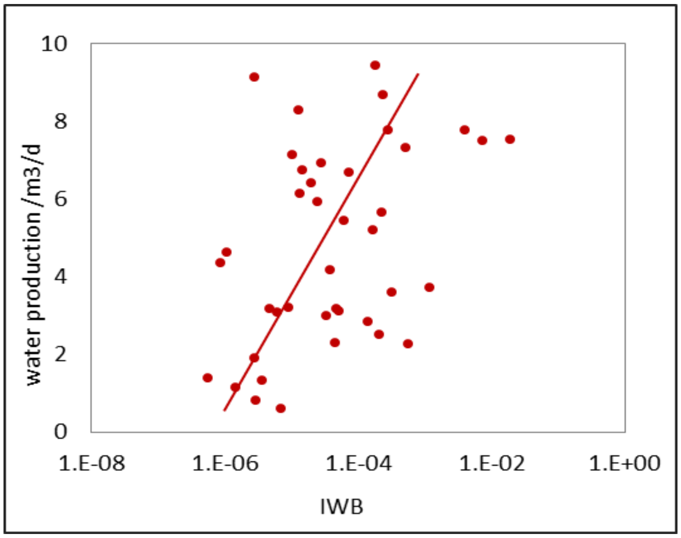

Figure 2 *the relationship between daily average water production and IWB of 44 CBM wells*

Moreover, to study the relationship between these two indexes (ICT and IWB) and DAP, a crossplot is shown in Fig. 3.

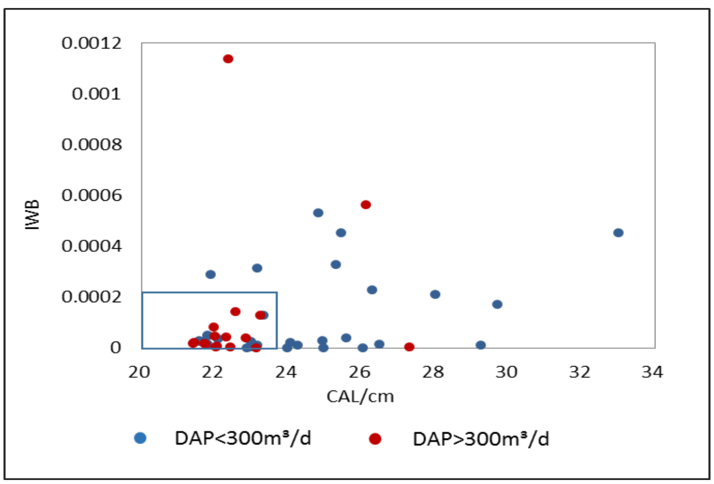

Figure 3 *the crossplot of CAL and IWB of 44 CBM wells*

According to Fig. 3, among a total of 44 CBM wells, when set the IWB<0.002 and CAL<23.8cm as the indication of high- and middle-yield (HM) wells, 13 out of 16 HM wells are selected rightly, and 18 out of 28 low-yield wells are selected rightly, with an accuracy of 70%. In this way, we define the quality factor of coal seam (Q_{cs}) as the combination of ICT and IWB, that is, if ICT<1 and IWB <0.0002, Q_{cs}=1; if not, Q_{cs} =0.

Critical desorption pressure (P_c) and the ratio of P_c to reservoir pressure (P_{cr})

In the early stage of gas production, if the burial depth is deep, the reservoir pressure is larger than the critical desorption pressure, even there is pressure drop, CBM cannot be desorbed. Once it comes to the critical pressure point, gas desorption becomes easy. Thus, two factors including critical desorption pressure (P_c) and the ratio of P_c to reservoir pressure (P_{cr}) are important to predict gas production, which are obtained by Langmuir isothermal adsorption equations,

$$P_c=V_{gas}P_L/(V_L-V_{gas}) \quad (8)$$

$$P_{cr}=P_c/P_r \quad (9)$$

Gas content (V_{gas}) and gas saturation (S_g)

In the same structural setting, a low gas content is equivalent to a low gas saturation. (Qiao, 2011). A small degree of undersaturation can necessitate prolonged dewatering before a large reservoir volume can reach the critical desorption pressure (Pashin, 2010). Therefore, a low gas content in the production section means a poor productivity, especially in the initial development stage. Similarly, a high gas content means a good productivity. Some studies have shown that gas production have a positive correlation with gas content, which is an essential part in this study.

Modeling and Results

Based on our discussions, when Q_{cs} equals 1, P_c and P_{cr} are large, V_{gas} and S_g are large, the gas production will be large. In this study, combining actual production data, a quantitative prediction method is shown in Tab. 1.

Table1 *the prediction method in SZN block*

	Q_{cs}	=1	=1	=0	=0
Prediction Method	P_c	>1.2	<1.2	>1.2	<1.2
	.or./.and.	.or.	.or.	.and.	.and.
	P_{cr}	>0.15	<0.15	>0.18	<0.18
Production=	V_{gas} * S_g *	3	2	1.5	0.1

Based on this method, we can get a prediction curve. In order to get an accurate value of DAP, we need to do the integral. Based on this method, the DAP of a total of 97 CBM wells in SZN block is estimated, in which 77 wells can be accurately classified as high-, middle- or low-yield wells, with an accuracy of 79%.

Conclusions

In this study, CAL and SP curves, which were rarely used before are verified to be important, getting coal texture index and water bearing index. Furthermore, these two indexes can get the quality factor of coal seam. Combining conventional logging data and production data, five important factors are put forward. Then, a quantitative model to predict gas production in CBM wells is established. This method is applied to forecast the potential of gas production. To verify this method, gas production of a total of 97 wells are predicted, with an accuracy of 79%. This indicates that in the further development, CBM wells can be accurately classified as different levels of gas production based on conventional logging data, which can save production costs. It can be used as a helpful tool in CBM investment and development.

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