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Research on Detection Indexes of Coalbed Methane Drainage Effect and Evaluation Method in Coal Mine Area

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The coalbed methane (CBM) drainage effect of surface drainage after 5 years in Jincheng mining area was detected using the numerical simulation and measured method. The surface drainage effect of CBM detected by the measured method is adopted first time in China. It was measured that the CBM content by surface drainage after 5 years was declined from 21.58 m^3/t to 10.47 m^3/t, and the average value of reduced rate of gas content was 50.2%. After 15.6 months and 29.6 months by underground mine drainage it was measured that the CBM content was declined from 20.1m^3/t to 11.24 m^3/t and 4.76 m^3/t respectively. According to the measured CBM content and the numerical simulation results of seam reservoir, combing with the practical experiences of CBM drainage in coal mine areas and the related management stipulations in China, and considering the safety of CBM drainage and the resource benefits in coal mine area comprehensively, it is suggested that the CBM content and the reduced rate (or recovery rate) of gas content are taken as the detection and evaluation indexes of CBM drainage effect in coal mine area, and the detection and evaluation technical methods of CBM drainage effect in coal mine area are established.

1. Introduction

The coalbed methane (CBM) is a kind of non-conventional natural gas which is originated from the coal seam and is mainly stored in coal seam, its main component is methane, and which is so-called as mine gas in coal mine (Zhang et al., 2016). The CBM is a disaster gas which results in the gas explosion and coal and gas outburst in coal mine and the climate warming, and the same time, the CBM also is a kind of new clean energy source. The development of CBM has the multiple effects such as safety, energy source and environment protection. The object of CBM development in coal mine area is to improve the safety condition of mine production, develop and utilize the resources, and reduce the emission of the greenhouse gas objectively.

Around the safety production in coal mine and the fully utilization of the resources, it adopts all technical measures which are could be adopted, such as the coal is mining after gas is drained, the gas content in coal seam is declined as far as possible before coal mining, the coal seam with the outburst hazard originally is transferred to the coal seam without the outburst hazard, and the high gas underground mine is transferred to the low gas underground mine (Hu, 2004; Zhang et al., 2007; Zhang, 2007; Shen et al., 2011; Yuan et al, 2013). In the underground mine, the seam gas pressure, CBM content and drainage rate are usually adopted as the detection indexes of the drainage effect of CBM, and in the trade standard the critical values of various indexes judging the CBM drainage reaching to the standard are stipulated from the angle of safety (Yang et al., 2013). From the angle of resources, the CBM drainage is usually adopted the gas production and recovery rate as the evaluation indexes of the CBM drainage effect. It had not been reported that the research on the detection and evaluation on the CBM drainage effect in coal mine area how to consider comprehensively the safety and resources.

With the deeply development of the CBM drainage in coal mine area in China, it needs to develop the research on the detection indexes and evaluation method of CBM drainage effect in coal mine area, in order to effectively guide the CBM development in coal mine area in China.

2. Screening of the detection indexes of CBM drainage effect in coal mine area

The detection and evaluation on CBM drainage effect in coal mine area are conducted the comprehensive evaluation mainly from two aspects: the safety and resources. The combined theory of coal and gas outburst is considered that the outburst is the result of the combined action of three factors: geo-stress, physical-mechanical properties of mine gas and coal. The gas factor plays the very important pole in the process of coal and gas outburst, without the enough gas content the outburst is difficult to occur, and even if the outburst is occurred it is mainly the extruding and emptying types. The high or low of the CBM content reflects the hazard degree of the gas disaster in the mining process of coal seam, and the higher the gas content, the larger the hazard degree of the gas disaster in the mining process of coal seam (Jin and Zhang, 2005).The related studies that the CBM content is taken as the prediction index of the seam gas hazard had been conducted (Hu et al., 2007). In the related stipulation and standard on the mine gas control in China the gas content already was listed as the detection index. Therefore, the CBM drainage effect evaluated from the safety angle is mainly to detect the CBM content.

Although there have more evaluation indexes (Jiang, 2010; Li et al., 2014), in which the CBM drainage effect is evaluated from the resources angle, however, the recovery rate is more visually in the aspect indicating the development and utilization degree of the resources, so the recovery rate is taken as an important index to detect the CBM drainage effect universally at home and abroad. According to the material balance principle, the drained CBM resource amount is equal to the reduced resource amount in coal seam, while the reduced resource amount in coal seam could be indicated by the product of the declined amplitudes of the coal resources and CBM content. It could be known from the definition of the recovery rate that the recovery rate of the CBM resources is the ratio of the drained CBM resource amount and the CBM resources amount before drainage, the coal reserve is not varied before and after the seam drainage, so the recovery rate of the CBM resource is the ratio value of the declined amplitude of the CBM content and the CBM content before the seam drainage substantially. The ratio of the declined amplitude of the CBM content after the seam drainage and the CBM content before the seam drainage is defined as the reduced rate of the gas content. The calculation equation of the reduced rate of the gas content is shown as Equation 1:

$$K = 100 \times \frac{W_0 - W_1}{W_0} \tag{1}$$

Where, K is the declined rate of the CBM content, %; W_0 is the CBM content before drainage, m^3/t; W_1 is the CBM content after drainage, m^3/t.

In the coal mine area, the detection process on the CBM drainage effect is conducted often through the measure on the reservoir parameters, and especially in the underground mine. Therefore, it is suggested that the reduced rate of the gas content is taken as the detection index of the CBM drainage effect from the resources angle.

3. Detection on CBM drainage effect in coal mine area

3.1 Detection on surface CBM drainage effect

(1) Digital simulation of the reservoir parameters

The CBM-SIM reservoir digital simulation software is adopted to conduct the reservoir digital simulation on a well group in the Jincheng mining area, and the variation relationship of the CBM content with the drainage time is drawn based on the simulation results, as shown in Figure 1 and Figure 2.

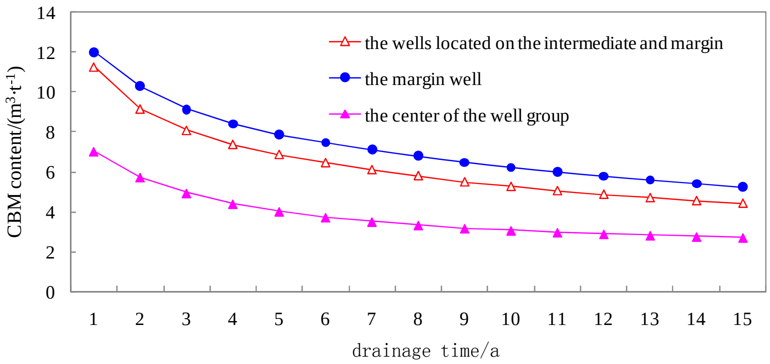

Figure 1: Variation rule of single well CBM content by simulation within well group

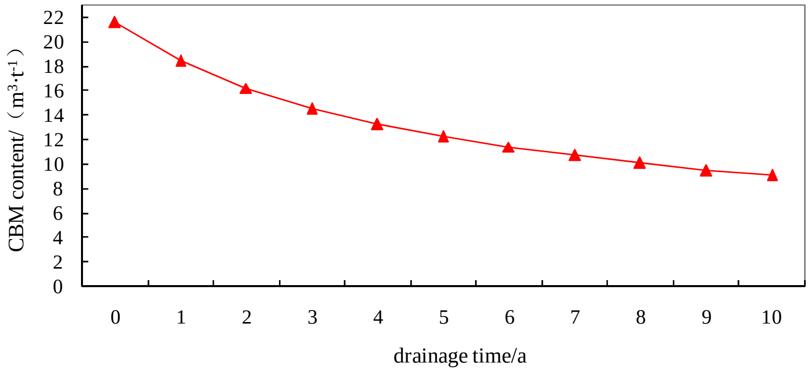

Figure 2: Variation rule of average CBM content by simulation within well group

From the figures it can be seen obviously that with the extension of the drainage time, the CBM content is declined obviously; for the drainage wells which are located in different locations within the well group, the rates of their CBM content declining variation are different, the CBM content declining rate of the well located on the center of the well group is larger than that of the wells located on the intermediate and margin, while that of the intermediate well is larger than that of the margin well; the average CBM content declining rate of the well group is lower than that of the single well. After it was drained by 5 years, 10 years and 15 years, the average value of the CBM content declining rate within the well group was 43.33%, 58.20% and 65.80%, respectively.

Using numerical simulation results of single well, the paper had predicted the CBM content of ground drainage respectively for 5 years and 10 years within well group(Fig.3，Fig.4). From Fig.3, after ground drainage for 5 years within well group, the result is that the CBM content was generally lower than $12m^3$/t, and less than $8m^3$/t only in the smaller areas near the extraction well. The CBM content in the surrounding area was generally greater than $14m^3$/t. From Fig.4, it could be seen that the CBM content was generally lower than $8m^3$/t after ground drainage for 5 years within well group, and in the surrounding area the CBM content was generally greater than $12m^3$/t.

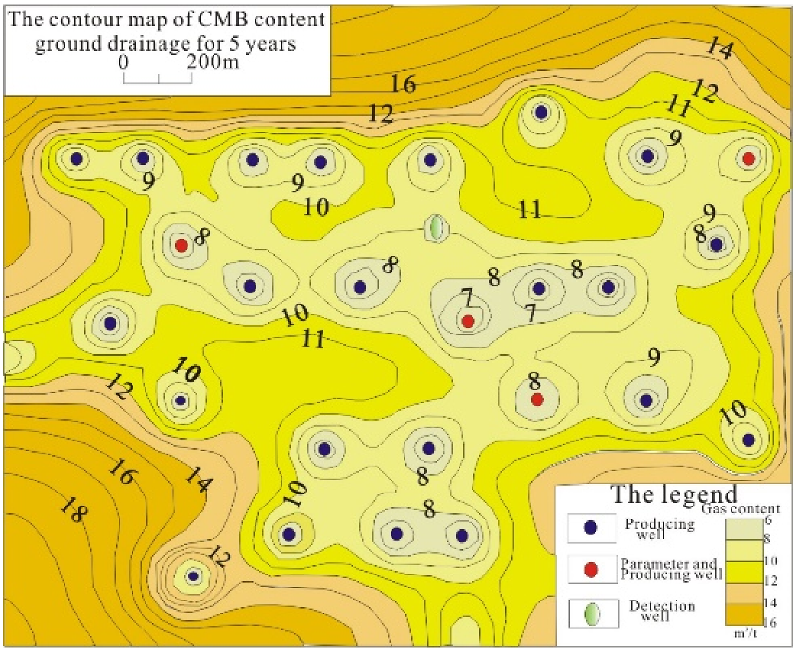

Figure 3: The simulation results to predict CBM content of ground drainage for 5 years within well group

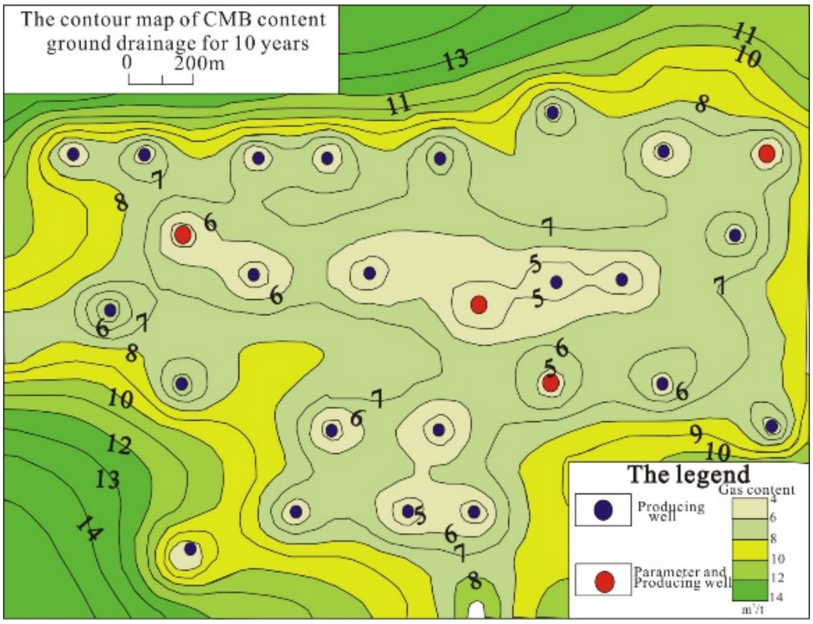

Figure 4: The simulation results to predict CBM content of ground drainage for 10 years within well group

(2) Reservoir parameters measuring

In 1981, the measuring on the CBM content after surface drainage by 4 years was conducted in the Oak Forest in Black Warrior Basin, USA, and it was measured that the CBM content was 6.7 m^3/t (the CBM content before drainage was 14.2 m^3/t). In 1988, the measuring on the CBM content in seam was conducted again, and it was measured that the CBM content was 3.8 m^3/t(Ayoub et al., 1991; Zhang and Zhao, 2010). In this study, a parameter well was constructed within a well group which had conducted the surface drainage by 5 years in the Jincheng mining area. The distance between the detection well and surrounding drainage wells is 209.76-355.31 m, and about 300m in general. The CBM content was 21.10-21.90 m^3/t, in average 21.58 m^3/t. The coal core was sampled adopting the wireline coring method, the CBM content was measured according to the “Measuring method of coalbed methane content” (GB/T 19559-2008, and the measured results are listed in Table 1. From Table 1 it can be seen that the CBM content after the surface drainage by 5 years was 8.97-12.45 m^3/t, in average 10.74m^3/t, and the reduced rate of the CBM content was 42.3%-58.4%, in average 50.2%.

Table 1: Measured results of CBM content after surface drainage by 5 years

CBM content before drainage /($m^3 \cdot t^{-1}$)	Drainage time /a	CBM content after drainage /($m^3 \cdot t^{-1}$)	Reduced rate of CBM content /%
21.58	5	8.97	58.4
		12.45	42.3
		11.40	47.2
		10.58	51.0
		10.29	52.3
Average value		10.74	50.2

3.2 Detection on underground CBM drainage effect

In the Jincheng mining area, the CBM content of No.3 seam is high, and the seam belongs to the easy drainage seam. The CBM drainage in underground adopts mainly the drainage patterns such as seam-parallel borehole, seam-penetrating borehole, goal area and so on; it adopts the 1000-m borehole or seam-penetrating borehole to conduct the regional pre-drainage before development in general, and after the working face is formed it conducts successively the pre-draining using the seam-parallel borehole within the scope of the working face (Wang et al., 2010). In order to inspect the variation situation of the CBM content after the seam drainage in underground, in underground mine of the Jincheng mining area it had conducted the measuring and arranging on the regional CBM content after drainage by 15.6 and 27.6~29.6 months, the

CBM content measuring accorded to the "Direct measuring method of coalbed gas content" (GB/T 19559-2008), and the measured results are listed in Table 2.

Table 2: Measured results of CBM content after different drainage time in underground

CBM content before drainage/($m^3 \cdot t^{-1}$)	Drainage time/a	CBM content /($m^3 \cdot t^{-1}$)		Reduced rate of CBM content/%		Number	Remark
		Region	Average	Region	Average		
20.1	15.6	7.7~17.7	11.24	11.9~61.5	44.0	397	Regional drainage before development
	27.6-29.6	3.94~5.7	4.76	71.6~80.4	76.3	7	Regional drainage after working face formed

From Table 2, it can be seen that it adopted the 1000-m borehole to conduct the regional drainage before the development, after it was drained by 15.6 months, the CBM content was declined from 20.1 m^3/t to 11.24 m^3/t, and the reduced rate of the gas content was 44.0%. After the working face was formed it constructed successively the drainage boreholes to conduct the regional drainage within the scope of the working face, after it was drained again by 12~14 months, it was measured that the CBM content was 4.76 m^3/t, and the reduced rate of the gas content was 76.3%.

4. Detection indexes and evaluation method of CBM drainage effect in coal mine area

4.1 Detection indexes and evaluation method of surface CBM drainage effect

According to the experiences from the USA, the service time of the CBM well is about 15 years in general. Based on the statistic results of the reservoir digital simulation of the surface CBM drainage from partial areas in China, after the drainage by 5 years the recovery rate of the CBM was 14.54% ~ 40.76%, after the drainage by 10 years the recovery rate of the CBM was 30.80% ~ 60.93%, and after the drainage by 15 years the recovery rate of the CBM was 40.65% ~ 71.58%. According to the reservoir digital simulation and the measured results of the surface reservoir parameters of the Jincheng mining area in this time, as well as the statistic situations of other mining areas, based on the drainage by 5 years, 10 years and 15 years, taking the reduced rate (or recovery rate) of the gas content and the CBM content as the detection and evaluation indexes, the surface CBM drainage effect of the coal mining areas is evaluated as three types: "good", "moderate" and "poor", and the concrete evaluation scheme is shown in Table 3.

Table 3: Detection indexes and evaluation method of surface CBM drainage in coal mining areas

Reduced rate (or recovery rate) of gas content/%			CBM content/($m^3 \cdot t^{-1}$)			Evaluation result
5 a	5~10 a	10~15 a	5 a	5~10 a	10~15 a	
>35	>45	>50	<10	<8	<6	Good
20~35	30~45	40~50	10~12	8~10	6~8	Moderate
<20	<30	<40	>12	>10	>8	Poor

4.2 Detection indexes and evaluation method of underground CBM drainage effect

According to the practical experiences of the underground CBM drainage projects in coal mines and the related stipulations on underground mine gas drainage management in China, and based on the detection results obtained in this research process, it is suggested that the CBM content and the reduced rate (or recovery rate) of the gas content are taken as the detection and evaluation indexes for the underground CBM drainage effect in coal mine, and the underground CBM drainage effect of the coal mine is evaluated as three types: "good", "moderate" and "poor", and the concrete evaluation scheme is shown in Table 4.

Table 4: Detection indexes and evaluation method of underground CBM drainage in coal mine

CBM content/($m^3 \cdot t^{-1}$)	Reduced rate (or recovery rate) of gas content/%	Evaluation result
<6	>70	Good
6~8	50~70	Moderate
>8	<50	Poor

5. Conclusions

In this research, based on the detection practices of the surface and ground CBM drainage effect in the typical coal mining areas in China, it was measured that the CBM content by surface drainage after 5 years in the Jincheng mining area was declined from 21.58 m^3/t to 10.47 m^3/t, and the reduced rate of gas content was 50.2%. After 15.6 months and 29.6 months by underground mine drainage the CBM content was declined from 20.1m^3/t to 11.24 m^3/t and 4.76 m^3/t respectively, and the reduced rate of gas content was 44.0% and 76.3%, respectively. According to the measured CBM content and the numerical simulation results of seam reservoir, combing with the practical experiences of CBM drainage in coal mine areas and the related management stipulations in China, and considering the safety of CBM drainage and the resource benefits in coal mine area comprehensively it is suggested that the CBM content and the reduced rate (or recovery rate) of gas content are taken as the detection and evaluation indexes of CBM drainage effect in coal mine area, and the detection and evaluation technical methods of CBM drainage effect in coal mine area are established, and it provides the basis for effectively guiding the CBM drainage in coal mine areas in China.
Due to the complicated seam geological conditions in China, the geological conditions and the CBM contents of various coal mining areas are differed largely, and this research is applied only in the Jincheng mining area practically. With the rapid progress of the CBM development in the coal mine areas in China, this evaluation yet needs to popularize and apply to other coal mine areas continuously, accepts the detection of the production practices wider, and the critical values of the detection indexes and the evaluation effect should be improved further.

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