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Gas control technology and engineering practice for three-soft coal seam with low permeability in XuanGang region, China

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Abstract

Underground coal mining needs effective technical methods for the control of gas emissions in order to be able to work under safe conditions. Based on the coal seam geological conditions among the Xuan Gang region, a major part of theoretical research and technical development has been directed to this purpose. According to the roles of mining fractures development and relief gas flow, a novel method for the comprehensive gas drainage was proposed and engineering practiced in the mining field, which includes long drilling boreholes, oblique crossed boreholes and upper corner flexible drainage pipelines. Compared with previous gas control measurements, the total gas drainage ratio significantly enhanced from 30% to 67.33% (No.51109 working face) and 76.44% (No.51105 working face). The ventilation air methane concentration of working face greatly decreased down to about 0.3%. Field tests shows that it is an effective method for gas control, which ensured the safety production of underground coal mine. The proposed gas drainage technology provides a novel approach for the three-soft coal seam gas management in China.

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Keywords: Gas emission; Three-soft coal seam; Low permeability; Relief gas drainage; Drilling hole

1. Introduction

China is abundant in coal, and the production of coal in 2010 had been reached about 3.25 billion tons, which occupied more than 70% of energy supply. However, another fact is that 17.6 percent state-owned key coal mines have the coal and gas outburst danger due to the high methane contents, high gas pressure and low permeability of coal bed, which threats the safety production, causing the human lives and facility losses in many cases. In order to reduce the outburst accidents, the National Coal Mine Safety Supervision

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Bureau issued the "Provisions of the Prevention of Coal and gas outburst" in August 2009, which emphasized the necessary of gas control measures especially for safety mining of "three-soft coal seam with low permeability".

Among all the coal reserves in China, the percent of thick coal seams achieve about 44% and the coal production from thick coal seams could be reach to about 45%. And now, fully mechanized top coal caving had been become a popular method especially for thick coal seam mining because of its high yield, high efficiency and low cost. But with the development of mining depth, the increased gas contents and pressure also enhanced the probability of accidents occurrence. Therefore, gas control technology developing for high gassy fully mechanized top-caving face has become a difficult problem needed to be resolved urgently for Chinese coal mines [1-4].

Engineering practice showed that, the advances of mining face always cause movement or destroy of coal bed and rock and lead to release of in-situ stress. The produced fractures greatly increase the permeability of coal seam and promote the flow characteristics of relief gases. Stress relief gas, refers to the gas which is deposited in the gob and fractured coal seams caused by mining. Reference to the seams being mined, relief gas can be divided into two main categories: gas distributed in the mined coal seams and that in adjacent coal seams, which will always discharge to the working face and cause serious accident of gas accumulation on the working face. Therefore, the gas control technology and its application on the working face of three-soft coal seam seem great important for safe mining. In this paper, the relationship between the stress relief, rock deformation and permeability of coal seam had been investigated. A gas control technology had been issued and applied in Jiaojiazhai mine, XuanGang region.

2. Basic theories analysis of stress and permeability

2.1. Rock layer deformation and permeability

Coal can be considered to be a naturally fractured reservoir where the permeability is governed by the fluid conductivity of the cleat, and of other structures present on a broader length scale. Researches show that permeability in coal is very sensitive to the effective stress, increasing as the effective stress relief [5]. When a coal seam has been mined, the stress equilibrium around the roof would be broken and redistributed, which would cause deformation, destruction and re-displacement of overlying strata. In order to control the roof effectively, many researches were carried out on the rock mass above the mined coal seam. Academician Qian of the China Academy of Engineering put forward "masonry beam model" and "key stratum theory" [6], and professor Xu promoted the key stratum theory for relieved gas control [7]. The rock surrounding the mining area can be divided into three zones in each of the section and plan views (Figure1). In the vertical section above the roof, the rock layers can be divided into a caved zone, a fractured zone and a bending zone [8].

The caving zone is deposited by pieces of rocks with various sizes bank up in the gob and has a relatively high void space providing a high permeability. With the advances of working face, the caving zone would gradually be suppressed due to the collapse of overlying strata, but it never reaches the original volume and still retains plenty of connective fracture. The fractured zone develops an abscission layer and vertical broken fractures. According to the connectivity of fractures, the fractured zone can be divided into penetrative zone (having a better permeability) and non-penetrative fractured zone (having a relatively worse permeability). The rock layer in the bending zone remains unbroken. The part below the bending zone develops the abscission layer, with few abscission events in the top part of the bending zone. Therefore, in order to gain a effective gas drainages, borehole should be drilled in the fractured zones.

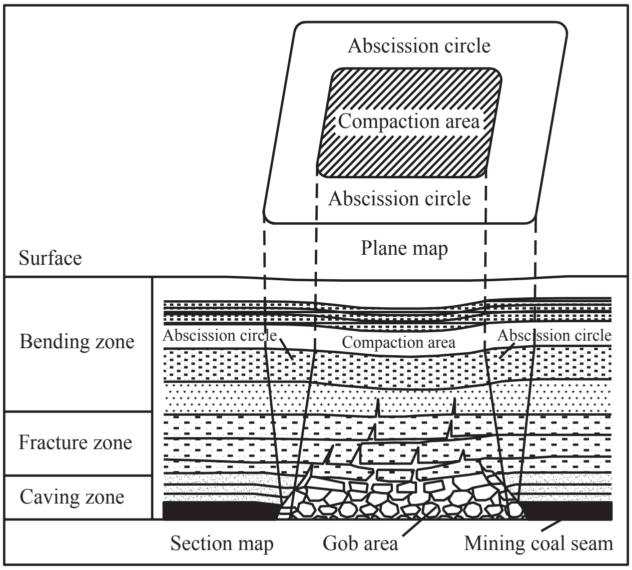


Figure 1 Vertical distribution of mining fractures in overlying rocks and the schematic diagram of "abscission circle"

2.2. Stress redistributions and permeability in mining area

With the advances of mining face, a variation of stress in front of the working face would be redistributed, which always cause various deformations in the rock mass. The weights of overlying rock are supported by the barrier pillar and the stress would decrease to a limited extent above the gob roof, whereas the stress around the working face is increased greatly. The stress redistributions around the working face would always cause the coal rock stretched or compressed, so as to deformed and fractured. According to the re-distributions of the stress (Shown in Fig.2), the regions around the working face can be divided into five zones: a normal stress zone (A), a stress concentrated zone (B), a stress relief zone (C), a stress resuming zone (D) and a re-compressed zone (E).

For the original coal seams, there are abundant primary cracks in the coal rock mass. Researches show that the permeability and fluid flow patterns in the coal rock masses are greatly sensitive to the effective stress on it, because it always distributed fracture aperture and also correlated with fracture traces [9-12]. With the increasing of norm stress, the cracks would be shrunk, whereas the cracks would expand while the norm stresses decreasing. Figure 2 shows that, with the mining processing, stress of coal bed in front of the working face experienced an obviously concentrated and released process. Near the working face where the stress is near zero on the open coal wall which is uncovered because of mining, but remains quite high internally in the seam. Under the function of redistribution and evolution of pre-brace stress, coal rock in front of the working face suffered a compress and expanding processes. Movements of the stress field result in the formation and development of fractures in the mined seam of the coal wall. On the other side, secondary fractures are formed in the coal as it breaks anisotropically. The local stress field, together with coal rock heterogeneities and interfaces (discontinuities; fractures, contacts), determine fracture propagation, deflection (along discontinuities/interfaces), thereby, its permeability development [13].

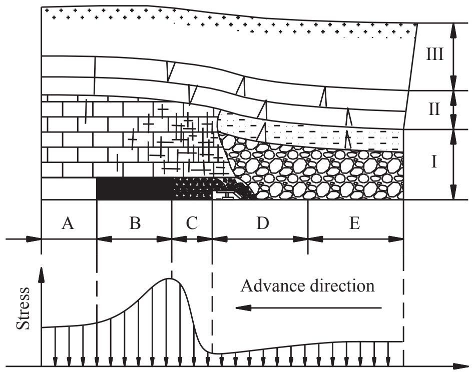


Figure 2 Horizontal stress distributions of overlying coal seam and rocks and the zone partitions

2.3. Gas flow and concentrated characteristics in the fracture zones

With the progress of mining, relief gas from the in-situ coal seam and adjacent layer will be concentrated and deposited in the fracture zones. For the bending zones, its penetrability was also increased obviously because of the formation of plenty of transverse clefts. Gases from adjacent seams would also be transferred along the travelling channels to the in-situ coal seams. Besides, the zones of fracture and bending are evolved with the advances of working face. Especially for the working face with "U" type ventilation system, under the pressure of ventilation air, relief gases of the gob zones will be transported along the fractures and concentrated in the top corner zones, which always cause gas-exceeding accident (Shown in Figure 3). Therefore, management of relief gases concentrated in top corner zone seems playing an important role for the gas control of working face [14].

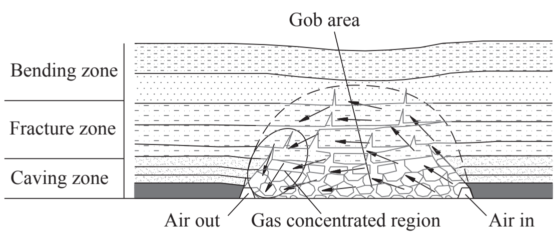


Figure 3 Gas flow and concentrated situation in gob zone of in-situ coal seam

3. Relief gas control technology

3.1. Coal mine summarization

JiaoJiaZhai mine of belongs to Ningwu coal field, under the management to the Datong Coal Mine Group. The thickness of No.5# mining coal seam is about 5.8-13.0meter, that is one of the main coal seam can be mined among the field. The coal spontaneous combustion duration is about 3-6 months, belongs to type II spontaneous combustion coal. According to the geological sense, No.5# coal seam is a single monoclinic structure and the average dip angle is about 12o. By the tectonic stress, the coal body is very soft and easy fragmentized. The working face of No.51109, which is used for the mining of No.5# coal seam, employed fully-mechanized caving method and U type ventilation mode for the coal mining. The lithology of coal stratum is shown in Figure 4.

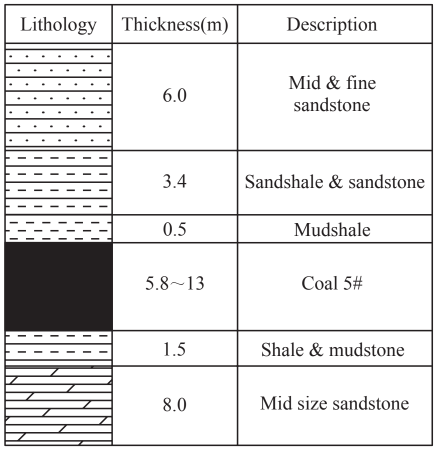


Figure 4 Lithology of coal stratum in JiaoJiaZhai mine, XuanGang region

3.2. Statistics laws of gas emission and its composition

Since 2004, there are total four working face had been mined for No.5# coal seam. After a large number of observations and statistics on the gas emission phenomenon, it can be concluded that gas emission in No.5# coal seam has the following significant features. The first is that the emitted gas quantity and concentration at the top corner and the tail of coal slide machine are great high, especially for last one, where gas concentration can be higher to about 2%. More importantly, this area may become a blind region of gas emission management. The second law is that gas emission quantity and concentration to the working face shows periodical regularity. With the progress of mining, the basic roof behind the working face will be caved and filled to the gob area. Affected by the roof caving, large quantity of gas released from the residual coal and concentrated in the gob area would be emitted to the working face in a short period, which often causes gas overloaded and alarm would continue for about 3-4 hours. More seriously, it may cause working staff asphyxia. Using elemental method [15], the gas emission quantity and its compositions were measured and list in Table 1. It can be seen that gob gas emission made a greater contribution to working face gas accumulation. Therefore, the drainage of gob gas and stress relieved gas seems critical for the working face emitted gas management and control.

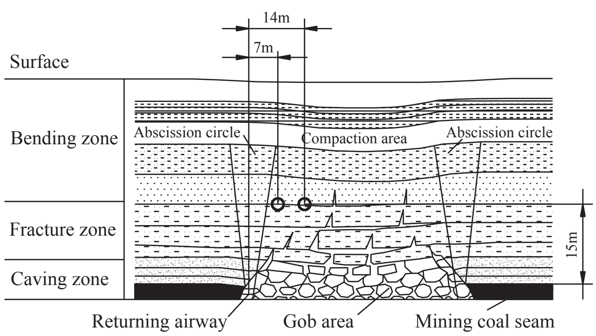
Table 1 Gas emission composition of working face in No.5# coal seam

Coal seam No.	Total quantity of gas emission (m^3/t)	I-Gas emission from coal wall (m^3/t)	II-Gas emission from gob area (m^3/t)	Percent of part-I (%)	Percent of part-II (%)	Working face level (m)
5#	10.35	2.26	8.09	21.8	78.2	-1020m
5#	15.44	5.34	10.10	34.6	65.4	-820m
Coal production of No.5# seam at 51109 working face: 3000t/d						

3.3. Proposed gas control technology for three-soft coal seam of XuanGang region

Based on the distribution and evolution of mining stress and fracture, according to the gas transportation and accumulation of relief gas, a comprehensive method by "3D drainage technical" are selected for the emitted gas control to the working face in Xuangang region. This drainage method includes long drilling boreholes, oblique crossed boreholes and upper corner flexible drainage pipelines.

On the foundation of XuanGang mine region actual geological conditions, FLAC3D software was used for the determination of fracture zones. And fully taking into account gob fire prevention, the long drilling boreholes were placed in the junction point of caving zone and fracture zone in the vertical direction. In the horizontal direction, the drilling boreholes were placed about 15meters inside return airway tunnel, the schematic diagram of the long drilling holes' allocations are shown in Figure 5. The oblique crossed boreholes are mainly used for the pre-drainage of relief gas from the mining coal body, and both used for the extraction of gob gas at the same time. These clustered holes were drilled at the drill section in the return airway tunnel. The oblique crossed boreholes were placed at the direction to the coal wall with the angle about 30-35^{o} to the return airway tunnel in the horizontal direction, and with angle of elevation about 15-20^{o}, which is shown in Figure 6. The lengths of these clustered holes were about 50m, and the end of holes will drilled into the roof of the 5# coal seam about 5meters. In order to reduce the probability of emitted gas accumulation at the upper corner, and at the same time to reduce the burden of gas drainage by long drilling boreholes, several flexible gas drainage pipes were inserted into gob areas at the upper corner section, which is shown in Figure 7.



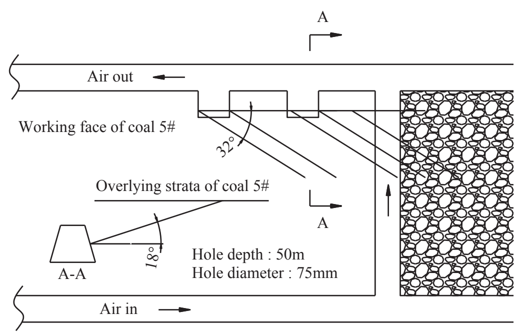


Figure 5 Allocations of 1000m length drilling holes **Figure 6** Allocations of oblique crossed boreholes in air returning gateway

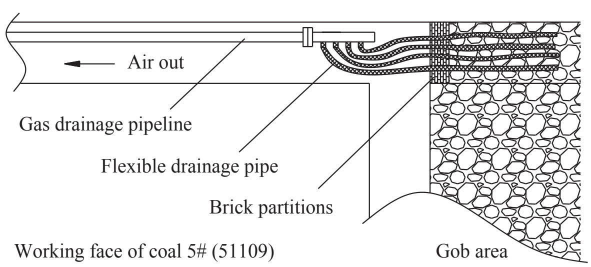


Figure 7 The upper corner gas control by gob drainage pipe technology

4. Engineering applications and results discussions

4.1. Construction of drilling holes and drainage systems

Employed VLD1000 drilling systems (Figure 8), the long holes were drilled in the roofs of No.5# coal seam, along the direction of working face advanced and parallel to the air returning way. The specific location parameters of long drilling holes are shown in Figure 5 and the designed holes tracks are shown in Figure 9. Due to the effect of coal geology, the depth of ZK1 hole were drilled about 648 meters, and ZK2 hole were drilled about 585 meters, with the same diameter of 96 millimeter. Compared with the designed holes trajectory, the horizontal deviation range of ZK1 hole is the 0.10-0.50 meters, and the range of vertical deviation is the 0.30-4.50 meters. For the ZK2 hole, the horizontal deviation range of is the 0.50-2.50 meters and the range of vertical deviation is the 0.30-1.00 meters. At the same time, the deviation range of branching hole is about 1.00 meter in the horizontal direction and 0.50 meter in vertical direction (shown in Figure 10 and Figure 11).

The oblique clustered holes were constructed according to the Figure 6 and the end of holes will drilled into the roof of the 5# coal seam about 5meters. At the same time, the flexible gas drainage pipes were placed according to Figure 7. All the drilling holes were plugged using polyurethane materials and gas was extracted using mobile gas drainage pumping station (Model No. ZWY 40/75) underground coal mine.

Figure 8 VLD1000 type drilling system of Valley Longwall International Group Companie

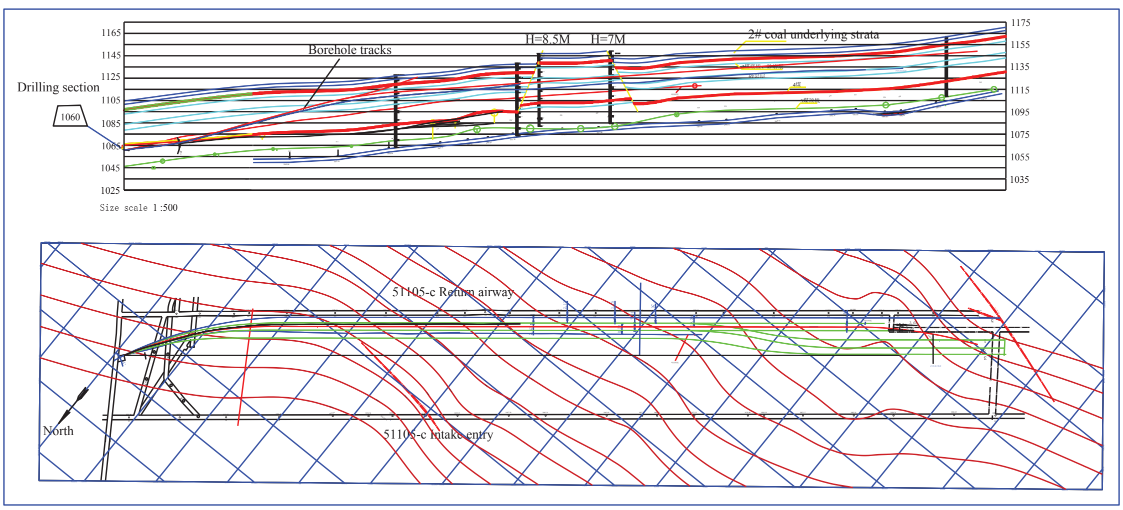


Figure 9 No.1 and No.2 drilled borehole track of 51109 working face in 5#coal seam of JiaoJiaZhai Colliery, XuanGang region

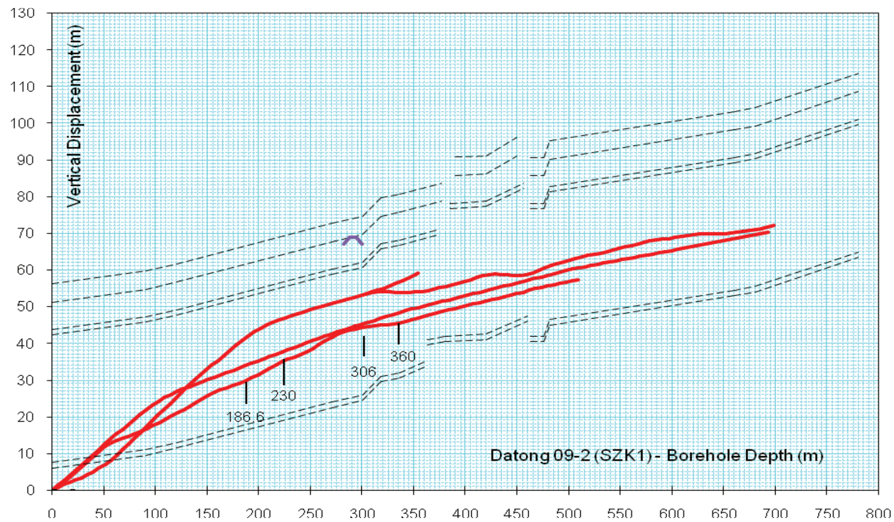


Figure 10 Displacement of ZK1 borehole in 51109 working face

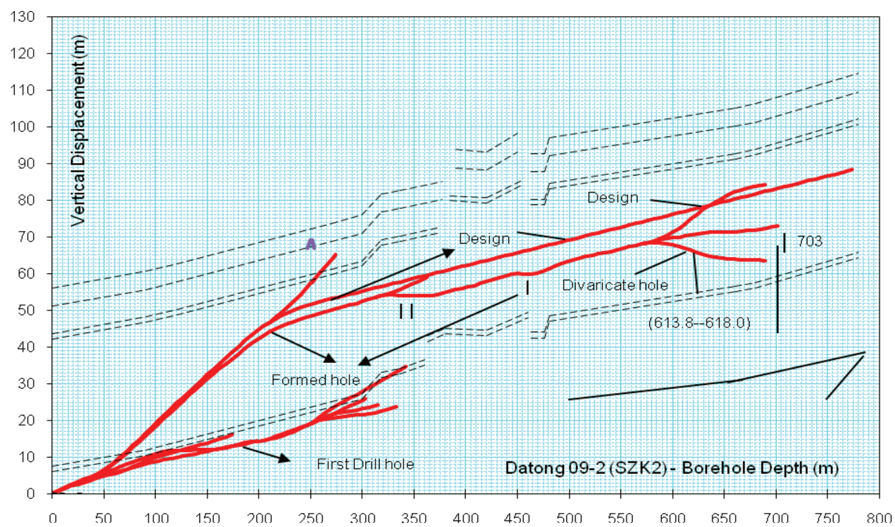
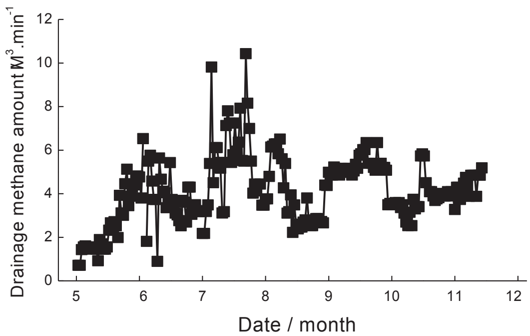


Figure 11 Displacement of ZK2 borehole in 51109 working face

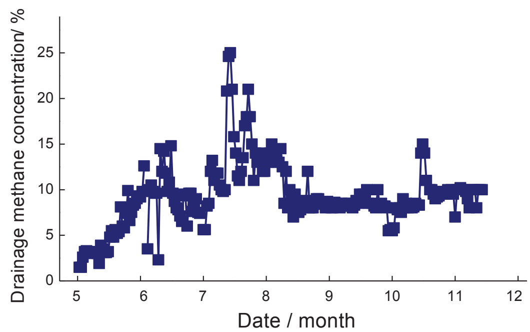
4.2. Gas drainage effects and analysis

Before the implementation of this technology, the upper corner gas drainage method and the horizontal parallel drilling holes along the bedding coal seam were employed for the gas drainage. Due to the low permeability of the coal seam, the coal seam gas drainage ratio can only reach to about 30%. Gas emission intensity was seriously stronger and unbalanced during the coal mining process. The maximum gas concentration in some local point among the working face can reach to about 2%, which seriously affect the safety of coal mining.

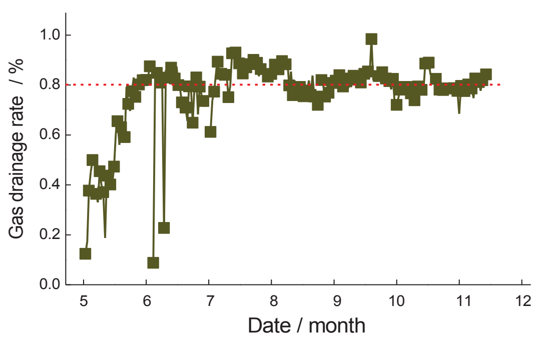
The "three dimensional gas drainage technologies" were applied successively in No.51109 and No.51105 working face in XuanGang underground coal mine region and the corresponding monitoring data are shown in Table 2, Table 3 and Figure 12. Compared with the previous drainage technology, the total gas drainage ratios were significantly improved from about 30% to 67.33% for No.51109 working face and to 76.44% for No.51105 working face. It can be seen that gas drainage by long drilling holes and oblique clustered holes plays an important roles in the gas emission management by 63.36% for the No.51109 working face and by 72.69% for No.51105 working face. From the monitoring data of gas drainage pumping station (Figure 12), it presents that the net gas drainage amounts are about 4.20 (m3/min) and gas drainage concentration maintains about 10% (volume). This gas drainage technology made the ventilation air methane concentration greatly reduced from the previous 2.0% to about 0.3% (with fluctuations range of 0.2%-0.4%), which ensured the safety production of underground coal mine.



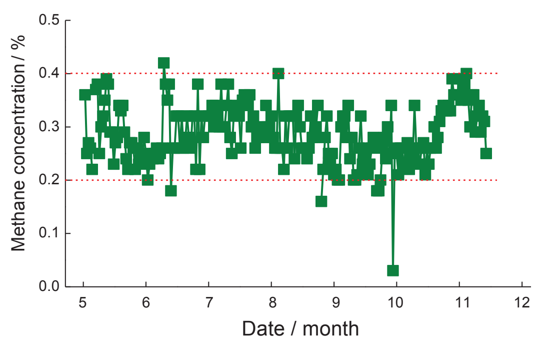
(a) Gas drainage amount



(b) Gas drainage concentration



(c) Gas drainage ratio



(d) Gas concentration in VAM

Figure 12 Gas drainage monitoring data vs. time (No.51109 working face)

5. Conclusions

Underground coal mining needs effective technical methods for the control of gas emissions in order to be able to work under safe conditions. Based on the coal seam geological conditions among the XuangGang region, a major part of theoretical research and technical development has been directed to this purpose. According to the roles of mining fractures development and relief gas flow, a novel method for the comprehensive gas drainage was proposed and engineering practiced in the mining field, which includes long drilling boreholes, oblique crossed boreholes and upper corner flexible drainage pipelines. Compared with previous gas control measurements, the total gas drainage ratio significantly enhanced from 30% to 67.33% (No.51109 working face) and 76.44% (No.51105 working face). The ventilation air methane concentration of working face greatly decreased down to about 0.3%, which ensured the safety production of underground coal mine.

Acknowledgements

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