FIELD TEST RESEARCH ON GAS MIGRATION LAW OF MINING COAL AND ROCK

by

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The fractures in coal and rock mass are the main channels of gas seepage, and understanding the gas migration law during mining is the precondition of gas control. The long-term in-situ monitoring of the abutment pressure, fracture networks and gas-flow in front of a mining face was carried out and the 1-D connectivity ratio of boreholes were calculated. The results showed that under the influence of mining, the fracture networks developed to the depth of rock stratum, and as far-field gas seepage channels, far-field gas continuously supplied the near-field gas. The gas flow in front of the mining face have undergone two stages of evolution from initial value to peak value, and then to a stable value. The 1-D connectivity ratio the abutment pressure about 5 to 10 m. The 1-D connectivity ratio reflected the dergree of coal and rock fracture penetration caused by mining, and the area with the highest gas extraction efficiency was the transition zone from peak abutment pressure to residual pressure in coal seams.

Key words: *gas migration, abutment pressure, 1-D connectivity, gas extraction, fracture network, field test*

Introduction

The migration law of gas in fracture medium is affected by many factors such as temperature, pressure and fracture parameters, but the theoretical study on gas seepage has been in the exploration stage [1]. Nationwide, more than 70% of the major accidents in which more than 10 people died in coal mines were gas explosions. Gas has become the biggest *killer* of coal mines in China [2]. The disturbance of coal mining not only cause damage and breakage of coal rock, but also provide environment for gas analysis and produce fracture network that provide channels for gas seepage and migration [3-5]. However, under the coupling action of mining stress and gas pressure, the spatio-temporal evolution law of mining associated fractures field and primary fractures field in overlying strata is extremely complex [6-9] .

Up to now, protective seam mining is the most economical and effective measure to prevent coal and gas outburst [10], and the evolution law of mining fractures and permeability changes caused by coal mining is the basis and key to gas control [11, 12]. Meanwhile, some studies have been made in this area. The change law of gas pressure in protective layer was

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obtained by Zhang *et al*. [13]. A theoretical expression of the mining-induced permeability change ratio was derived in [14]. The relevant relationship between fractures evolution, connectivity and abutment pressure was investigated [15]. The equivalent permeability analysis of 3-D discrete fracture network models was investigated [16]. The percolation theory of the connectivity characteristics of 2-D fracture networks was combined [17]. In general, these studies have provided great guidance in the understanding of gas seepage mechanism and gas control. However, the gas-bearing coal-rock geological body is under complex heterogeneity. In order to truly reflect the characteristics of gas seepage under the influence of mining, the main aim of the paper is to carry out the field monitoring tests of the borehole fracture peeping, mining abutment pressure and gas-flow in the roadway, and to reveal the gas migration law under the protective seam mining conditions.

Field test design

Geological conditions

The test site is the low-drainage roadway of No. 15-24080 mining face in the No. 4 mining area of Pingdingshan No. 10 Coal Mine. The ground elevation is +150 ~ +280 m, and the working face elevation is –580 ~ –660m. The designed strike length is 1804 m, while the average inclined length is 188 m, and the thickness of coal seam is between 1.6 m ~ 2.3 m. The geological structure of the mining face is relatively simple, the roof is mudstone and sandy mudstone. The lower part of No. 15 coal seam is No. 16 (protected layer) coal seam with a thickness of 1.25 ~ 1.43 m. In order to achieve the loosening and pressure relief of No. 16 coal seam, first mining No. 15 protective seam, then mining No. 16 coal seam. The No.15 coal seam is a coal and gas outburst coal seam.

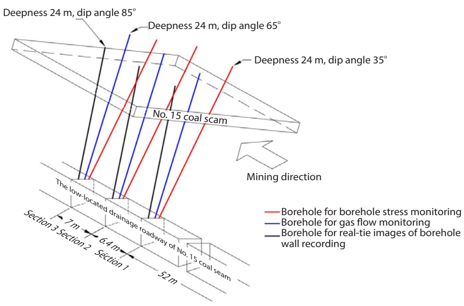

Figure 1. The 3-D sketch of monitoring section

Figure 2. The ZWS-I gas-flow meter

Monitoring section lay-out and test equipment

The purpose of the test was to reveal the gas migration law under the influence of mining. Three in-situ test monitoring sections were designed and numbered as section 1 ~ 3 in turn. The horizontal distance of the monitoring section according to the mining face was 52 m, 58.4 m and 65.4 m, respectively. Each monitoring section was equipped with three boreholes, including gas-flow monitoring borehole, fracture peeping borehole and abutment pressure monitoring borehole. The number of all types of boreholes were consistent with those of monitoring sections. Among them, the depth of gas monitoring borehole and abutment pressure monitoring borehole was 24 m with an inclination angle of 65° and 35°, respectively. And the depth of fracture peeping boreholes No. 1, No. 2, and No. 3 were 17 m, 17 m, 24 m, respectively, with an inclination angle of 85°. Spatial position relationship of each monitoring section and borehole orientation were shown in fig. 1.

Gas-flow monitoring adopted ZWS-I gas-flow meter, fig. 2, while a CXK12_Z borehole imaging instrument, fig. 3, was used for borehole fracture peeping, which could record the borehole wall image and depth of the probe automatically. The intrinsically safe borehole stress gauge was used to monitor the abutment pressure in front of the mining face. During the installation of the borehole stress gauge, the stress gauge was pushed to the bottom of the borehole through the guide pipe, and then poured with cement so that the strain gauge of the stress gauge could be closely attached to the borehole wall and transmitted force, so as to accurately monitored the evolution process of coal rock abutment pressure in front of the mining face.

Figure 3. The CXK12-Z borehole imaging apparatus

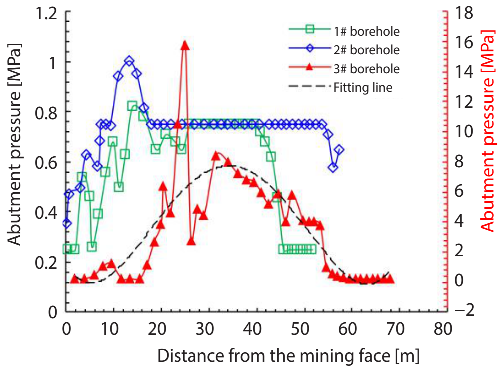

Figure 4. Abutment pressure monitoring results

Analysis of the field monitoring results

Evolution characteristics of abutment pressure of mining coal and rock

It is shown that the coal and rock permeability is very sensitive to in-situ stress, and mining stress is one of the most important factors affecting the change of coal seam permeability. Monitoring results showed that the evolution law of abutment pressure with the advancing of mining face roughly coincided with the trend of abutment pressure distribution curves under three typical mining conditions refined [18], fig. 4. Under the condition that tectonic stress was not dominant, the abutment pressure was in the hydrostatic pressure state outside the mining affected area, and then the peak stress appeared within a certain distance from the mining face. After reaching the strength of coal and rock mass, it began to decrease and finally fell to the residual stress.

It should be noted that the stress direction monitored by borehole stress meter was influenced by both mining abutment pressure and horizontal tectonic stress. The peak stress of section 3 increased significantly because of the dominance of tectonic stress, and the stress fluctuation was obvious at about 25 m of the mining face, which could not truly reflect the evolution trend of abutment pressure. From the evolution process of abutment pressure of borehole No. 1 and No. 2, it could be seen that the distance of peak abutment pressure was about 15 m from the mining face and the mining affected area was about 56 m from the mining face.

Development and evolution characteristics of mining coal-rock fracture network

Recorded images record by CXK12_Z borehole imaging apparatus from the beginning of borehole formation until the borehole being destroyed showed that there were three main types of fracture development in boreholes, including ordinary fractures, separation zone fractures, and fractured zone. In order to quantitatively described the fractures in boreholes, the aforementioned fractures were projected to the direction perpendicular to the roof, and the recorded images were vectorized in AUTOCAD software transforming into the fractures expansion map of the borehole wall. A typical vector diagram of the fractures evolution on the bore-

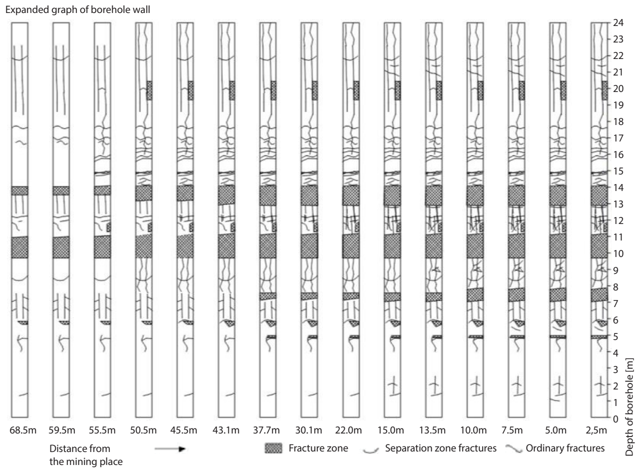

Figure 5. Typical vector map of fracture evolution in borehole wall

hole wall was shown in fig. 5 after the images of fracture peeping borehole No. 3 were processed.

The vector maps of fracture in borehole walls showed that with the advancing of mining face, the fractures in borehole continued to develop towards the bottom of borehole under the influence of mining. The area originally fractured became more fragmented, new mining fractures appeared around the main fractures and continued to develop and extended under the influence of mining, and some of the main fractures and new fractures formed new fractured zones. However, the opening degree of the main fractures in the separation layer decreased gradually when advancing near the fracture peeping borehole. Vector maps of fracture in borehole walls showed that the fracture development and expansion in borehole No. 3 was more complex than that in borehole No. 1 and No. 2, and there were fewer fractures in the early period of borehole No. 2, but under the influence of mining in the later period, the ordinary fractures and separation zone fractures in borehole wall increased rapidly while the fractures in the bottom direction of borehole No. 1 developed less.

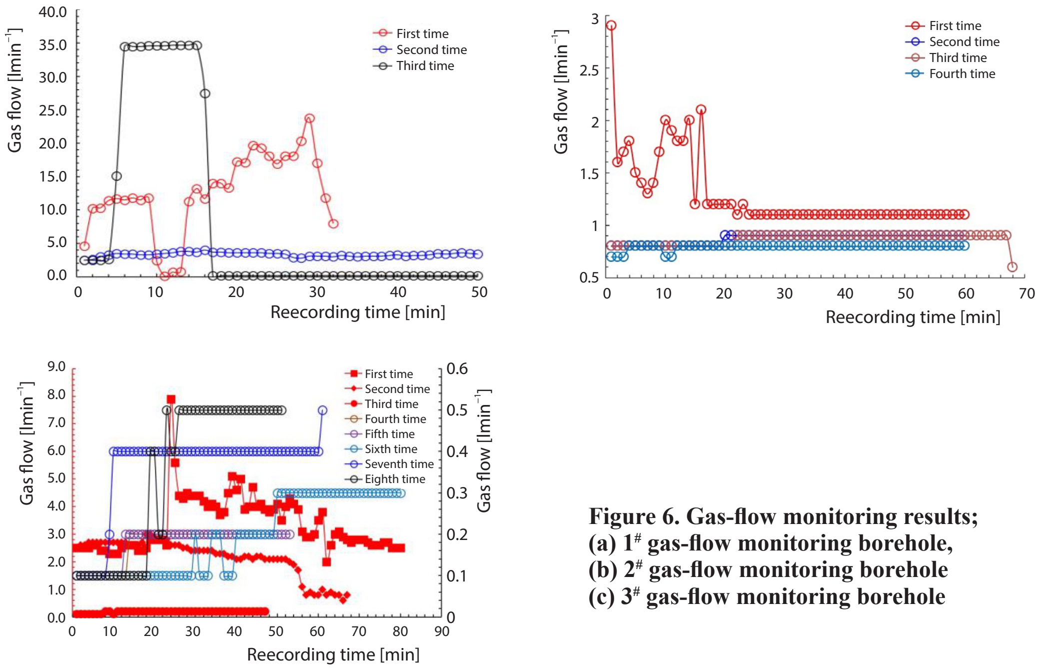

Figure 6. Gas-flow monitoring results; (a) 1# gas-flow monitoring borehole, (b) 2# gas-flow monitoring borehole (c) 3# gas-flow monitoring borehole

Dynamic evolution characteristics of gas-flow in mining coal and rock

To quantitatively evaluate the gas seepage characteristics under mining conditions, the gas-flow monitoring in boreholes was carried out. It should be pointed out here that different monitoring times corresponded to different monitoring periods (distance to mining face) in each figure, and the same monitoring times were monitored in the same period in figs. 6(a)-6(c).

The borehole monitoring results of gas-flow showed that the natural gas emission from No. 15 coal seam fluctuated greatly and rose gradually in the initial stage, and gradually decreased with time in the medium term, but finally stabilized. In fact, the evolution process of gas-flow could be understood as initial borehole penetration, gas gathering from primary fractures and mining associated fractures in coal and rock mass to borehole catheter, gas-flow gradually rose. In the mid-term, gas-flow gradually decreased due to near-field gas attenuation. And in the later period, mining fractures as far-field gas seepage channel continuously supplemented near-field gas, and gas-flow gradually stabilized. The stable gas-flow truly reflected the coupling state of gas pressure, mining stress and mining fracture field in coal and rock mass. It should be pointed out that some monitoring results fluctuated greatly due to catheter blockage and local geological structure in the process of gas-flow monitoring, but the overall evolution law accorded with the above evolution law of gas-flow.

Exploration of gas migration mechanism based on field test

In order to quantitatively evaluate the difficulty of gas seepage, the 1-D connectivity ratio along the borehole depth was calculated by applying the method mentioned in [19]. The 1-D connectivity ratio of boreholes along the depth of boreholes distributed in different intervals, and the influence of mining on the development and penetration of fractures was significant, fig. 7. Generally, the 1-D connectivity ratio presented a three-stage evolution model of slow increase, near linear increase, steady and gradually decrease with the advancing of mining face.

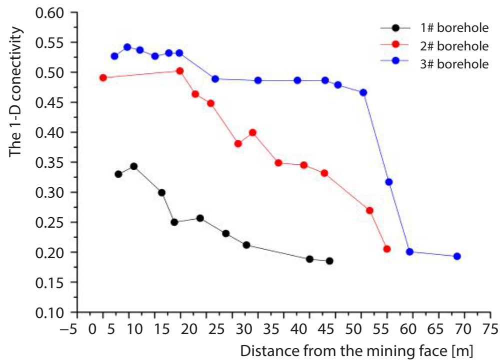

Figure 7. The 1-D connectivity ratio along the borehole depth direction

In order to comprehensively reflected the characteristics of gas migration in mining coal and rock, typical 1-D connectivity ratio curve, abutment pressure curve and average gas-flow curve were selected and plotted in fig. 8. It should be noted here that average gas-flow was selected after stabilization, and was taken in the corresponding time. At the same time, the distance between monitoring section and mining face was measured in the corresponding test time.

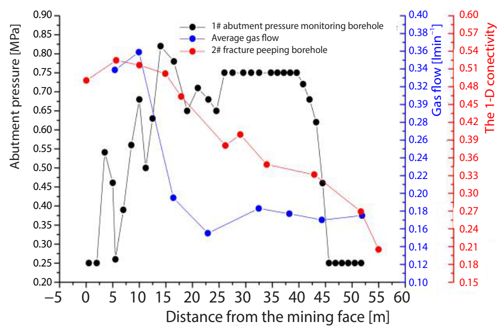

Figure 8. Correlation among abutment pressure, 1-D connectivity ratio and average gas-flow

With the advancing of mining face, 1-D connectivity ratio, average gas-flow and abutment pressure all showed a two-stage evolutionary pattern of first rising and then decreasing, fig. 8. The peak value of 1-D connectivity ratio and average gas-flow lagged behind the peak value of abutment pressure about 5 ~ 10 m. This lag phenomenon- further reflected the causal relationship between abutment pressure and permeability coefficient of coal and rock mass. As coal and rock mass gradually entered the mining affected area, primary coal seam fractures gradually expanded and generated ordinary fractures, resulting in the 1-D connectivity ratio, the average gas-flow and the permeability of coal seams increased gradually. With the further sharply increase of the abutment pressure, the growth rate of fractures and fracture penetration rate (1-D connectivity ratio) of coal and rock mass gradually accelerated, the average gas-flow showed an apparent acceleration simultaneously. After reaching the peak value, the expansion deformation and progressive failure of coal and rock mass occurred, the fractures developed further, the 1-D connectivity increased further, and the gas-flow increased sharply. When the coal and rock mass was reduced to the residual strength under the abutment pressure, the coal and rock mass gradually compacted, the fractures in the coal seam closed gradually, and the 1-D connectivity ratio decreased gradually, resulting in the gas migration blocked, and the gas-flow was decreasing gradually. From above it could be concluded that the gas migration was the result of multiple factors. The average gas-flow curve showed that the area with the highest gas extraction efficiency in the coal seam of No. 15-24080 mining face was 5 ~ 15 m in front of the coal wall.

Conclusion

In order to reveal the law of gas migration in front of coal and rock mass under the influence of mining in protective seam, in-situ monitoring tests of borehole fracture peeping, abutment pressure and gas-flow in mining coal and rock mass were carried out and analyzed, and 1-D connectivity of borehole wall in coal seam was calculated. The influence of mining caused the fracture network of coal and rock mass to develop and expand to the depth direction of the stratum, and the influence of mining on the fracture network of overlying coal rock along the mining direction was about 56 m. As gas seepage channels, the fracture network in the working face did affect the gas migration. The near-field gas was continuously analyzed and supplied by the far-field gas, which led to the gas pouring into the mining face. There was a causal relationship between the abutment pressure and the 1-D connectivity ratio of the coal seam in front of the coal wall. The evolution mechanism of them along the mining direction tended to be consistent. The 1-D connectivity ratio lagged behind the abutment pressure to a certain extent and it reflected the penetration degree of the fracture network of the coal seam. The gas migration mechanism was influenced by many factors. The 1-D connectivity ratio reflected the difficulty of gas migration and tended to be consistent with the peak position of gas-flow. The region with the highest gas extraction efficiency was the transition zone from peak abutment pressure to residual pressure in coal seam.

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