Kai Wang, Jie Zang*, Aitao Zhou*, Han Gao**

APPLICATION STUDY ON COOPERATIVE DRAINAGE TECHNOLOGY FOR MINING-AFFECTED PRESSURE RELIEF GAS IN OVERLAYING ADJACENT SEAMS**

1. Introduction

Yangquan mine area, one of the most difficult gas drainage mining area in China, has multiple coal seams and high gas emission [1]. Statistical analysis of gas sources in pairs of mine showed that the adjacent seams were the main sources of gas emission of mining faces, and whether this part of gas could be appropriately controlled would influence the safety production status of the faces and mine. Take mined faces of 12# coal seam in Nanzhuang mine for example, many years' on-site observations showed that the main gas sources of mining face of 12# coal seam were 12# coal seam, overlaying adjacent seams and lower adjacent seams. Calculation results indicated that the gas quantity emitting from the overlaying adjacent seams, which was the focus of drainage, accounted more than 85% gas emission of mining faces of 12# coal seam. For the purpose of draining this part of gas, high-located boreholes were arranged in tail roadway, which took a good drainage effect on the gas emitting from 8# and 9# coal seams, but the gas emitting from 11# coal seam and other overlaying adjacent seams which were closer to 12# coal seam was ineffectively controlled. This part of gas, which had a fast emitting speed and large quantity, often caused gas concentration exceeding limitation. In order to reverse this trend, measures like increasing air volume and limiting

* School of Resource & Safety Engineering, State Key Laboratory of Coal Resources and Mine Safety, China; University of Mining & Technology, Beijing 100083, China

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the production had been carried out. In such a case, however, not only the production efficiency was reduced, but the safety exploitation was constrained severely. Thus, new technologies for controlling the gas emitting from overlaying adjacent seams of 12# coal seam must be studied on.

Meanwhile, for 15# coal seam is the most major mining coal seam of Yangquan mine area, current studies focus on theories and technologies for draining the gas emitting from overlaying adjacent seams of 15# coal seam, but almost none of 12# coal seam. Therefore, based on mining faces of 12# coal seam in Nanzhuang mine, through the combination of theoretical study, numerical simulation and on-site observation, the enrichment law of mining-affected pressure relief gas in overlaying adjacent seams of 12# coal seam was analyzed, and based on this law, the cooperative drainage technology for draining this part of gas were explored. According to the on-site test and effect investigation, by applying this drainage technology, good economic, social and environmental benefits have been achieved, meanwhile, a safe, efficient, and sustainable exploitation of the mine has been realized.

2. Enrichment law of mining-affected pressure relief gas in overlaying adjacent seams

2.1. Generalization of test area

Nanzhuang mine, 12.59 km^2 in terms of mine area and 200 t/y of approved production capacity, is located in south of Yangquan City. The stratigraphic column of Nanzhuang mine (partial) is shown in Table 1.

The under mining coal seams now are 12# and 15# coal seams. The average thickness of 12# coal seam is 1.22 m, and the inclination is about 6°. Mining faces of 12# coal seam, of which the design length and mining height of were respective 180 m and 1.5 m, applied the complex mechanical strike retreating coal mining technology. And these faces arranged three roadways: a rail roadway as the return airway; a haulage roadway as the intake airway; a tail roadway as the special gas drainage gateway.

2.2. Distribution laws of stress and mining-induced fractures in overlaying strata

While the face mining, Key Strata existing in overlaying strata will control movements of the overlaying strata. According to the Key Strata theory [2–7], there are three key strata in overlaying strata of 12# coal seam: medium sandstone upper 9# coal seam (Key Stratum I), medium sandstone upper 10# coal seam (Key Stratum II), and fine sandstone under 11# coal seam (Key Stratum III). Positions of each key stratum are shown in Table 1. Key strata will determinedly affect evolution and distribution of stress field, displacement field and fracture field of the overlaying strata, and then the gas migration and enrichment status in each overlaying adjacent seam will be affected as well.

TABLE 1
Stratigraphic column (partial)

Lithology	Thickness/m	Remarks
8# Coal Seam	0.31	
Medium Sandstone	15.93	Key Stratum III
9# Coal Seam	0.28	
Mudstone	6.71	
Medium Sandstone	13.38	Key Stratum II
10# Coal Seam	0.18	
Mudstone	2.86	
K_4 Limestone	1.69	
11# Coal Seam	0.36	
Fine Sandstone	3.80	Key Stratum I
Sandy Mudstone	3.00	
Mudstone	3.00	
12# Coal Seam	1.22	
Mudstone	1.98	
Fine Sandstone	3.33	
Mudstone	1.98	
K_3 Limestone	3.06	
13# Coal Seam	0.31	

As can be seen in Table 1, the thickness of Key Stratum II is quite big, and meanwhile, this stratum separates the overlaying adjacent seams into two parts: 8# and 9# coal seams are upper Key Stratum II, under which are 10# and 11# coal seams. Figure 1 shows the stress status of each overlaying adjacent seam during 12# coal seam mining process. As is shown, while the face mining, stress of each overlaying adjacent seam began releasing. Subject to the influence of Key Stratum II, comparing to 10# and 11# coal seams, not only the releasing time of 8# and 9# coal seams was later, but the releasing range was less as well.

Figure 2 and 3 show the displacement field and the mining-induced fracture field of overlaying strata of 12# coal seam respectively. According to the mining-induced fracture theory [2, 3], after the face mined, the overlaying strata will be divided into „three vertical zones", namely caving zone, fractured zone and bending zone. As is shown in both figures, the height of caving zone is about 10 m and the fractured zone is about 45 m high, which are basically consitant with the on-site observations of Nanzhuang mine.

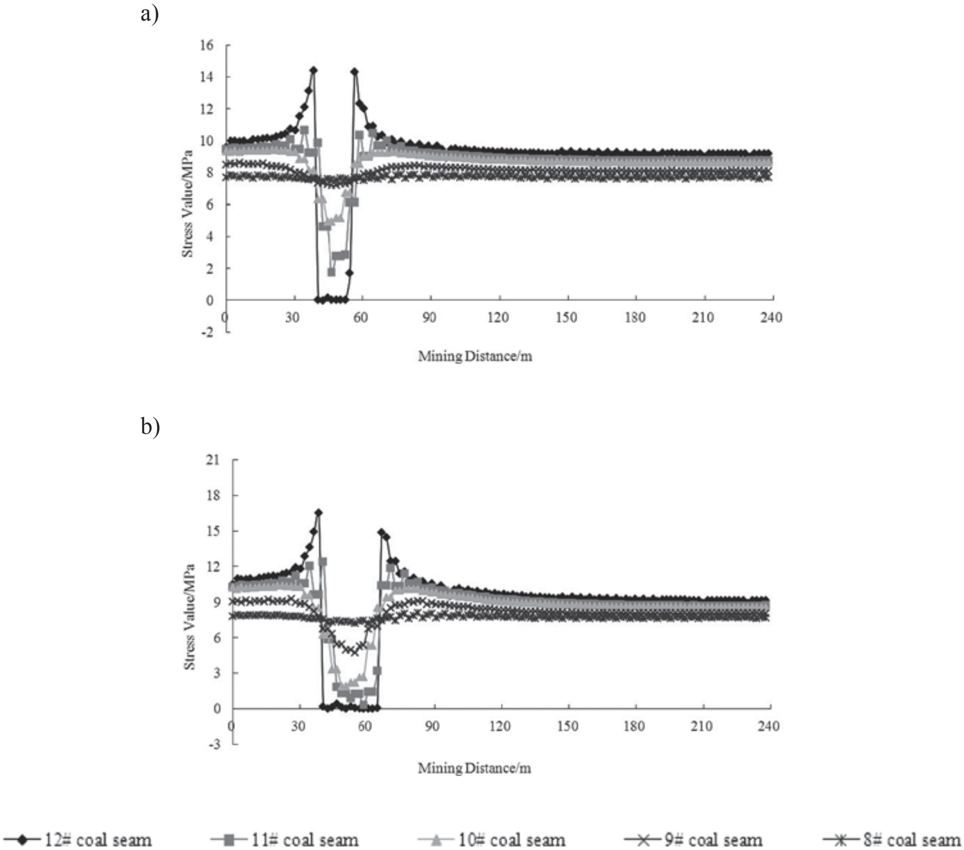

Fig. 1. Stress Status of Overlaying Adjacent Seams:
a) mining distance is 10 m; b) mining distance is 20 m

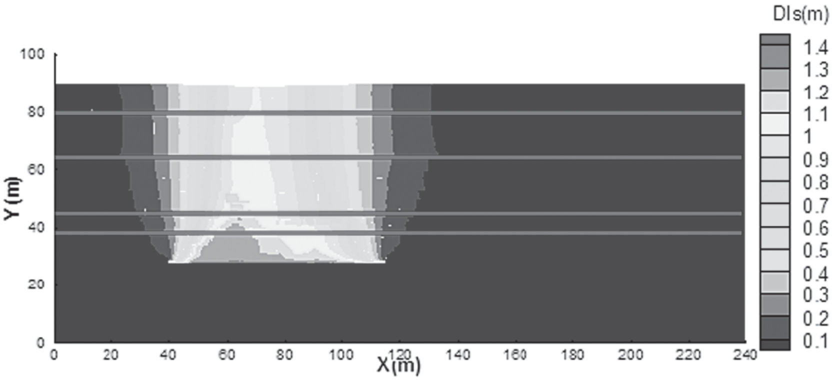

Fig. 2. Displacement field of overlaying strata

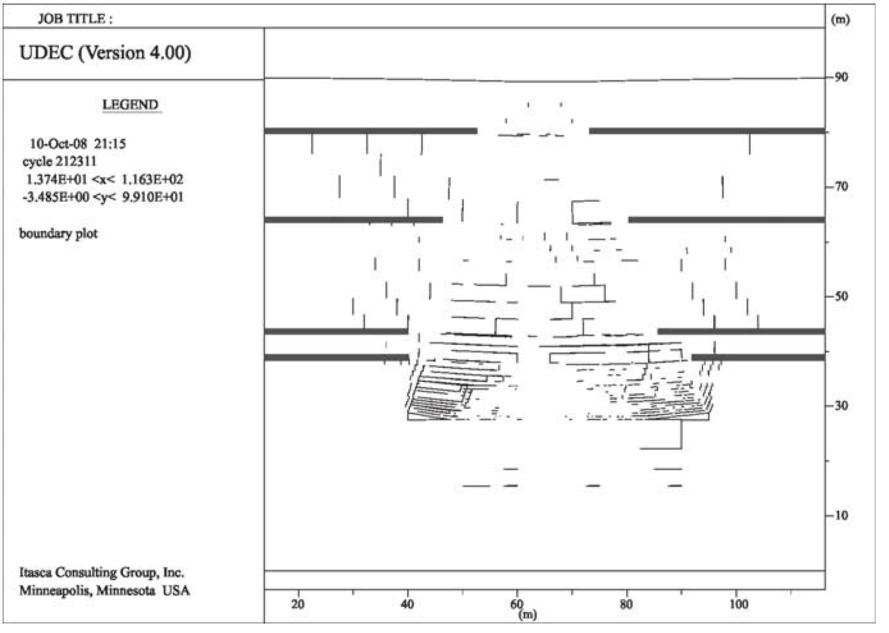

Fig. 3. Mining-induced fracture field of overlaying strata P.S. Red lines in figure 2 and 3 from top to bottom represent 8#, 9#, 10# and 11# coal seams respectively

From Figure 2 and 3, it also can be inferred that the strata under and upper Key Stratum II show different distribution characteristics in both displacement field and mining-induced fracture field: the former, which is located in the transition region of caving zone and fractured zone, has large displacements and intensive mining-induced fractures; while the latter, which is located in the transition region of fractured zone and bending zone, has small displacements and a little mining-induced fractures.

2.3. Zoning enrichment law of mining-affected pressure relief gas in overlaying adjacent seams

Through the above results it can be concluded that under the influence of Key Stratum II, 10# and 11 coal seams present different features in stress field, displacement field and fracture field with 8# and 9# coal seams: the former is located in the transition region of caving zone and fractured zone, which has large displacements and intensive mining-induced fractures, while the latter is located in the transition region of fractured zone and bending zone, which has small displacements and only a little mining-induced fractures. From theories about desorption and migration of mining-affected pressure relief gas [8–17], it can be deduced that 10# and 11# coal seams present different characteristics in gas migration and enrichment with 8# and 9# coal seams. The stress of 10# and 11# coal seams releases fast, and the area around is rich in mining-induced fractures, in which the mining-affected pressure relief gas rapidly fills and the low gas enrichment zone will come into being. While the stress of 8# and 9# coal seams release slowly, and there are only a little mining-induced fractures around, in which the mining-affected pressure relief gas fills and the high gas enrichment zone will be formed. Gas in the low enrichment zone emits to the mining face rapidly through the extremely thriving fractured fissures, while the gas in the high enrichment zone has a later impact on the mining face. These discrepencies in gas migration and enrichment costitute the high-low zoning enrichment mechanism of the mining-affected pressure relief gas in overlaying adjacent seams of 12# coal seam.

3. On-site test and effect investigation of cooperative drainage technology

3.1. On-site test

According to the high-low zoning enrichment feature of the mining-affected pressure relief gas and on-site experience, the cooperative drainage technology was proposed, namely arranging high-located and low-located boreholes to drain the gas respective in the high and low enrichment zone.

The cooperative drainage technology had been implemented in 4611 and 4606 mining faces of 12# coal seam in Nanzhuang mine, and 4611 mining face was the first testing face. Through the investigation of the drainage effect in 4611 face, some improvements had been carried out on the cooperative drainage technology, and the new drainage scheme was continually applied in 4606 mining face. Arrangements of the boreholes in 4611 and 4606 mining faces are shown in Figure 4 and 5.

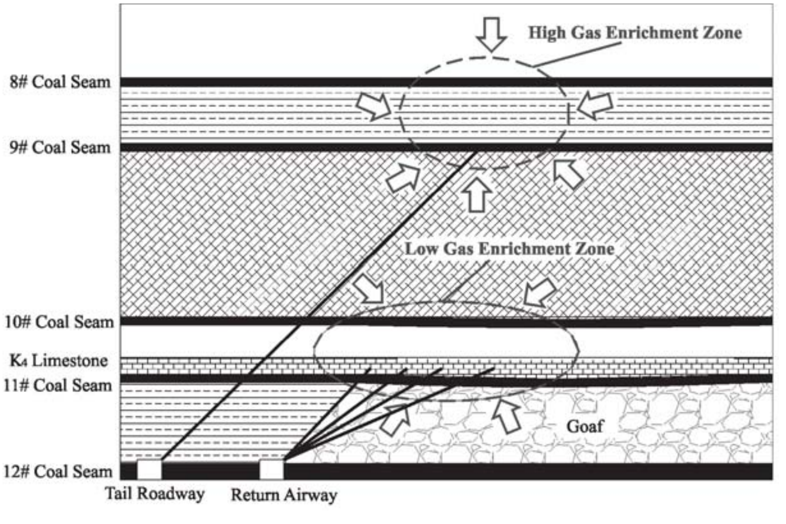

Fig. 4. Boreholes in 4611 Face

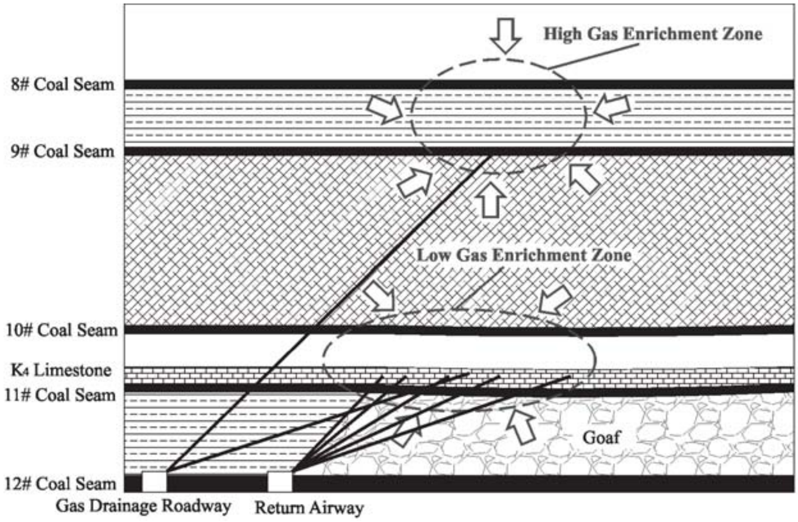

Fig. 5. Boreholes in 4606 Face

3.2. Effect investigation

Through applying the cooperative drainage technology, favorable benefits had been achieved in Nanzhuang mine:

1) The gas concentration in airways decreased, and the safety production status was remarkably ameliorated. After applying the cooperative drainage technology, none gas concentration exceeding limitation existed in 4611 and 4606 mining faces. In 4611 face, gas concentrations in the return airway, tail roadway, mining face and upper corner were respective 0.5%, 1.8%, 0.5% and 0.7%. While gas concentrations in 4606 mining face was even lower.
2) Both gas drainage rate and drainage quantity increased, and the methane discharge quantity decreased. Before using the cooperative drainage technology, gas drainage rate of mining faces of 12# coal seam was less than 65%, and drainage quantity was only about 38 m^3/min. However, drainage rate of both 4611 and 4606 mining faces were more than 85%, and both faces' drainage quantity were more than 50 m^3/min. In the whole mining period, the methane drainage quantity of both 4611 and 4606 faces were about 8.21×10^7 nm^3, and the methane discharging to the atmosphere was reduced by 63 225.55 t, which had an important significance for controlling the greenhouse effect.
3) The advance speed was accelerated, and the productivity was improved. Before applying the cooperative drainage technology, the advance speed of mining faces of 12# coal seam was only 2 to 2.5 m/d, and the monthly production never exceeded 30 000 t. While the advance speed of 4611 and 4606 mining faces exceeded 4 m/d, and the monthly production exceeded 35 000 t.

4) From March 2009 to November 2011, Nanzhuang mine had utilized methane 8.15×10^7 nm^3 (mainly from the gas drained from 4611 and 4606 mining faces), and about 80 million RMB was gained, among which, 5.32×10^7 nm^3 was sold to Yangquan Gas Company and 24 million RMB was gained, 1.57×10^7 nm^3 was used for power generation which was internal use only and 27 million RMB was saved, 1.26×10^7 nm^3 was used for other purposes and 8 million RMB was gained. In addition, the national financial subsidy for coal seam gas utilization was 20 million RMB.

In a summary, by applying the cooperative drainage technology, the safety production status of mining faces of 12# coal seam in Nanzhuang mine has been significantly ameliorated, advance efficiency, drainage rate and drainage quantity have been improved greatly, carbon emission has been reduced and the environment has been protected, resource utilization has been improved, service life of the mine will be extended. Finally, good economic, social and environmental benefits have been achieved, meanwhile, a safe, efficient, and sustainable exploitation of the mine has been realized.

4. Conclusions

1) Through the combination of theoretical study, numerical simulation and field observation, the high-low zoning enrichment law of mining-affected pressure relief gas in overlaying adjacent coal seams of 12# coal seam was formulated.
2) According to the zoning enrichment law, the cooperative drainage technology was proposed, namely arranging the high-located and low-located boreholes to drain the gas respective in the high and low enrichment zones.
3) By applying the cooperative drainage technology, the safety production status of mining faces of 12# coal seam in Nanzhuang mine has been significantly ameliorated, advance efficiency, drainage rate and drainage quantity have been improved greatly, carbon emission has been reduced and the environment has been protected, resource utilization has been improved, service life of the mine has been extended. Finally, good economic, social and environmental benefits have been achieved, meanwhile, a safe, efficient, and sustainable exploitation of the mine has been realized.
4) During the primary mining period of 4606 face, the gas drainage quantity was relatively low, while gas emission in the face was quite high. From now on, the gas control technology matching the primary mining period will be studied on, and the integrated gas control technology system which takes the cooperative drainage technology as the core will be revised.

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