JUNXIANG ZHANG
and
BO LI

Study on the reasonable number of demolished pre-drainage boreholes drilled along coal seams

In order to determine the reasonable number of demolished pre-drainage boreholes drilled along coal seams, against the backdrop of actual coal mines, the paper considered the comprehensive impact of pressure-relief ranges of the coal seams in front of the mining face, the advance rate of the working face, and drainage radius on the number of demolished pre-drainage boreholes. By means of numerical simulation and engineering verification, the paper determined the pressure-relief range of the coal seams in front of the mining face as 8.0m. Based on in situ mining progress and the relative production program, on the premise that the advance rate of the mining face remained constant, the paper analyzed the number of boreholes to demolish in front of the mining face at different gas pre-drainage time. The result showed that: when the gas pre-drainage time was defined as 30d, 60d and 90d, respectively, and the daily advancing distance of the working face was set as 3.6m at the same time, the number of boreholes to demolish was calculated to be 3, 3 and 2, respectively. This research result may act as a guidance to the reasonable deployment of mining programs in the coal mine, and may coordinate underground mining and gas extraction. It can also help realize coal seam outburst elimination and safety production to the greatest extent at the same time when economic benefits are maintained.

Keywords: *Demolished pre-drilled boreholes, advance rate, drainage radius, pressure-relief range, gas extraction.*

1. Introduction

As the mining intensity has mounted up in China, shallow coal resources are on the verge of depletion, steering the Chinese mining industry toward deep mining. Against this background, gas pressure and gas contents in coal seams continue to ramp up, and corresponding kinetics-induced accidents and disasters happen frequently. Thanks to the capacity of rapidly reducing or eliminating coal seam outbursts, the technology of borehole-based gas pre-drainage has been widely applied to mining work prior to the formation of the mining face, aiming to ensure underground coalmine safety production [1-2].

In the course of underground coalmine production, to satisfy production requirements at the mining face, it is supposed to demolish a certain number of pre-drilled boreholes (namely borehole demolition) that fall into a limited distance from the mining face. Overmuch demolished boreholes may become the culprit of coal seam outburst such that it endangers underground coalmine safety production; while insufficient borehole demolition will jeopardize normal operation of underground mining. Therefore, the reasonable number of demolished pre-drainage boreholes not only meets the demands of normal working progress, but also serves to eliminate the danger of gas accumulation in coal seams by realizing maximum extraction of the stored gas. In terms of determining the reasonable number of demolished pre-drilled boreholes, it is necessary to consider the comprehensive influence of pressure-relief ranges of the coal seams in front of the mining face, the advance rate of the working face, and drainage radius. Currently, there have been plenty of studies on pressure-relief ranges of the coal seams in front of the mining face and drainage radius. For example, in the form of field measurement, B. Liang [3], S. W. Li [4] and L. Zheng [5] determined drainage radius through the methods of pressure drawdown tests, flow tests, and gas tracer analysis, respectively. H. Si, et al. conducted simulative computation on drainage radius on the foundation of gas flow theories [6-8]. By using the simulation experiment with similar materials, G. Z. Yin [9] studied the changing law of pressure-relief ranges for roofs and floors of the goaf under the influence of mining. B. Li [10] established a mechanical model of coal seams around the roadway with the help of theoretical analysis, and also obtained the pressure-relief range of the roadway through theoretical calculation and numerical simulation. Through on-spot monitoring of the change of borehole stress and gas flow concerning the coal seams in front of the working face, K. Wang [11] determined the pressure-relief range of the

Messrs. Junxiang Zhang, School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo 454 000, and Bo Li, College of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo 454 000, Collaborative Innovation Center of Coal Work Safety, Henan Province, Henan Polytechnic University, Jiaozuo 454 000, Collaborative Innovation Center of Coalbed Methane and Shale Gas for Central Plains Economic Region, Henan Province, Jiaozuo 454 000 and Henan Key Laboratory of Biogenic Traces and Sedimentary Minerals, Henan Polytechnic University, Jiaozuo 454 003, China. Email:anquanlibo@163.com

working face. However, there is little research on the reasonable number of demolished pre-drainage boreholes drilled along coal seams in front of the mining face. In the context of actual coal mines, the paper took into consideration the comprehensive impact of pressure-relief ranges of the coal seams in front of the mining face, the advance rate of the working face, and drainage radius on the number of demolished pre-drainage boreholes. By means of numerical simulation and in situ engineering verification, the paper determined the reasonable number of demolished pre-drilled boreholes, which is of great instructive significance to underground coal mine safety production.

2. Analysis of factors that influence the reasonable number of demolished pre-drilled boreholes

In terms of determining the reasonable number of demolished pre-drilled boreholes, it is necessary to consider the comprehensive influence of pressure-relief ranges of the coal seams in front of the mining face, the advance rate of the working face, and drainage radius. Specifically,

(1) The advance rate of the working face is determined by the mining and production program, and is closely linked to the coal output and the economic benefit of the mining party;

(2) Drainage radius falls into the allowable interval where the gas pressure and gas contents stay within safety limits at the time when the borehole-centered coal seams are undergoing gas extraction. As coal gas continues to be extracted, the drainage radius gradually increases and finally reaches a maximum value;

(3) Pressure-relief ranges of the coal seams in front of the mining face appear when the original stress state of the coal seams in front of the coal mining face changes with mining activities. According to the distance from the mining face, the coal mines ahead of the mining face can be classified into the pressure-relief zone (nearest), the stress concentration zone (intermediate), and the elastic zone (farthest). The coal seams in different zones have different stress states and deformation properties, which will change with time.

Under the influence of mining, the deformation, breakage, and gas flow of the coal seams in front of the coal mining face act as a complicated coupling process. Given this, theoretical analysis, numerical simulation, and on-site verification were used to conduct systematic analysis of the comprehensive action mechanism of the stress change, distribution characteristics of coal permeability, and gas flows concerning the coal seams ahead of the coal mining face. Through research, the reasonable number of demolished pre-drilled boreholes was determined. This provides technical support for safe and efficient coalmine production, and plays an important role in guiding high-performance gas extraction as well as safety mining at the working face.

3. Determination of pressure-relief ranges of the coal seams in front of the mining face

3.1 Engineering background

As the 2-2 coal bed, the N2903 fully-mechanized coal mining face occurs in the middle of Shanxi Formation. With a stable horizon, it acts as the major working seam in the well field. The mining zone of the N2903 mining face pertains to local gas abnormal areas, where the grade classification of the propensity for spontaneous combustion lies in the level of ?, which means that it has no potential for coal-dust explosion. The mean length of bearing for the N2903 mining face equals 938m, and the slant length 174.8m. The coal depth concerning the N2903 mining face is in the range of 1.5m to 3.8m, with the average depth of 2.94m. As a whole, the mining face has the monoclonal structure at the coal seam dip angle of 2°?9°, the average angle being 3°. The ground level is +31.90?+32.20m, while the mining face level is -698?-752m. The initial total stress amounts to 21.86MPa, and the coal gas pressure equals 0.34MPa. The N2903 mining face employs the fully-mechanized full-seam one passing mining technology, and treats the goaf roof with full caving mining approach.

3.2 Author information

3.2.1 Model construction

Based on the coal seam occurrence conditions of the N2903 fully-mechanized mining face of a certain coal field in Henan, the paper established a corresponding geometric model. In light of the model, the coal seam had a height of 2.94m. The upper part of the coal bed was covered with overburden, and the lower part with floor. The coal seam specimen underwent excavation, where the mining face height amounted to 3m, and the width of the model 100m. Fig.1 is the sketch map of the geometric model, in which there was a total of 559,064 units.

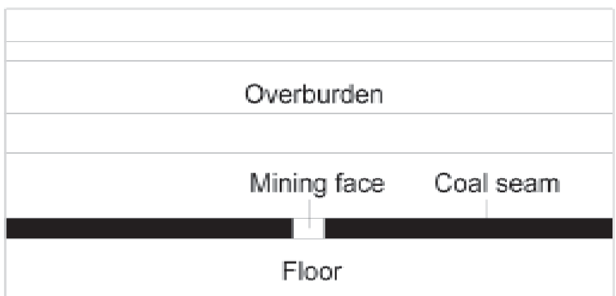


Fig.1 The sketch map of the geometric model

Relative parameters of coal seams and gas to the model are shown in Table 1.

The initial conditions and the boundary conditions were: the initial gas pressure in the coal seam was 0.34MPa, and the free coal seam roof was loaded with 12.86MPa coal strata gravity. The bottom of the coal seam specimen was fixed with roller support. Inside the model was self-weight load.

TABLE 1: PARAMETERS OF COAL SEAMS AND GAS

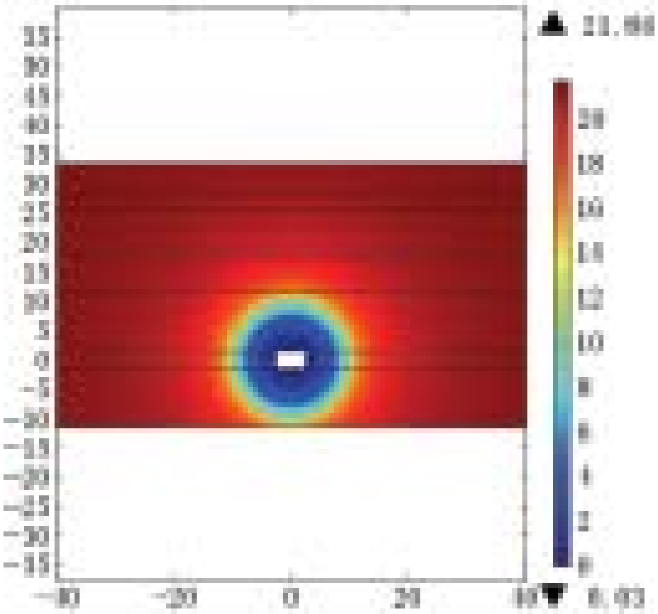
Parameter	Value
Depth	750m
Porosity	0.09
Initial permeability	$2.14\times10^{-17}m^2$
Gas pressure	0.34MPa
Coefficient of kinetic viscosity	1.08×10^{-5} Pa.s
Poisson's ratio	0.3
Modulus of elasticity	3×10^9GPa
Adsorption constant a	$26.67m^3/t$
Adsorption constant b	$1.39MPa^{-1}$
Water proportion	1.28%
Ash proportion	13.69%
Volatile proportion	8.83%
Supporting resistance	0.5MPa
Cohesion	2.5MPa
Angle of internal friction	30°

3.2.2 The simulation results of the stress change for the coal seams in front of the mining face

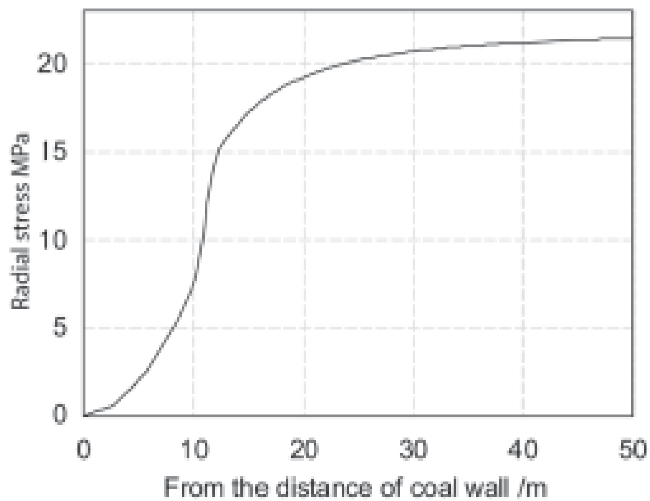
Fig.2 and Fig.3 are the simulation results of the radial stress and the tangential stress of the coal seams in front of the mining face, respectively. As could be seen, the stress was 0MPa near both ends of the roadway. In terms of radial stress, along with deeper mining, the radial stress rose gradually until it was restored to the initial stress state of 21.86MPa; in the light of tangential stress, the stress was 0MPa in the vicinity of coal walls at the mining face; as the distance from the coal wall increased, the tangential stress gradually increased. There appeared the plastic zone at the distance of 8.0m. The tangential stress peaked at 28.25 MPa in the elastic-plastic boundary that was 8.4m far from the coal wall, and reduced all the way to 21.86 MPa along with the advancement of the mining face. The simulation results demonstrated that the stress state of the coal mass was smaller than the initial stress in areas within 8.0m from the coal wall. Therefore, the pressure-relief range of the coal seams in front of the mining face could be obtained as 8.0m.

3.2.3 Simulation results of the permeability change of the coal seams in front of the mining face

Fig.4 is the curve of the permeability change of the coal seams in front of the mining face. The figure shows that the coal seam permeability exceeds the initial permeability within 8.0m from the coal wall, and falls gradually as the mining face advances forward. The reason for the first increase and next decrease of permeability is: along with the advancement, the stress state of the coal seams in front of the mining face changes, and the coal mass within the pressure-relief zone has already suffered damage and deformation, following the connection and enlargement of bores and cracks in the coal seams; while the gradually intensified stress on the coal seams in the plastic zone exerts compressive force on the coal seams such that the bores and cracks close, causing the permeability to restore to the initial value.



(a) Cloud map of the radial stress change



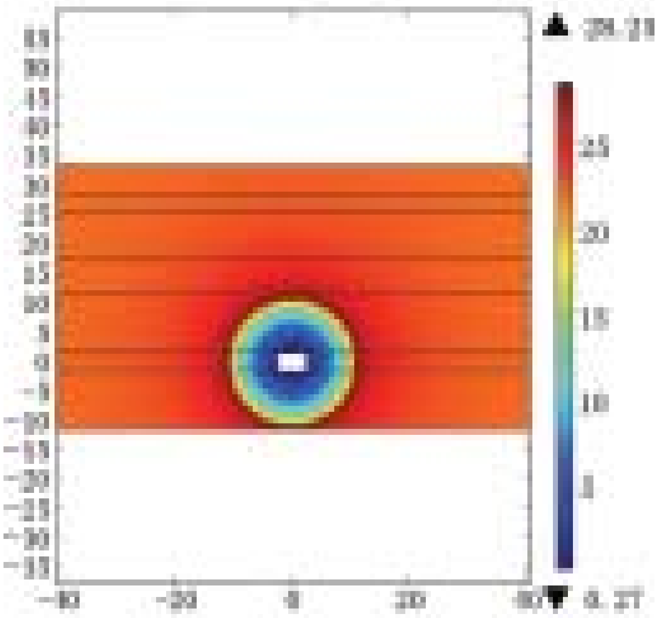
(b) Curve of the radial stress change

Fig.2 Radial stress change

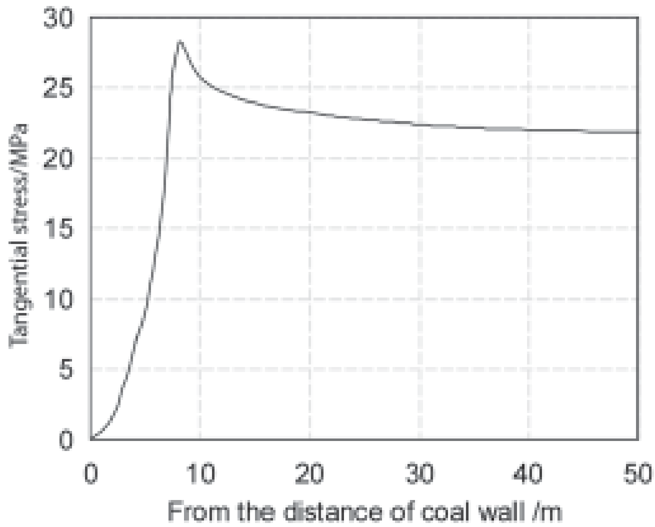
3.3 ENGINEERING VERIFICATION

The borehole flow method was employed to research the pressure-relief range of the coal seams in front of the N2903 mining face, which was determined by monitoring the records of gas flow for pre-drainage boreholes drilled along coal seams in front of the N2903 mining face. Figure 5 shows the curves of gas flow change that is monitored with the installation of 20# gas extraction borehole, 30# gas extraction borehole, and 76# gas extraction borehole, respectively.

According to the simulation results of stress and permeability of the coal seams in front of the mining face,



(a) Cloud map of the tangential stress change



(b) Curve of the tangential stress change

Fig.3 Tangential stress change

these coal seams underwent buckling failure and formed the pressure-relief zone. The favorable penetrating cracks in the zone developed into gas flow channels, and the gas emission volumes tended to rocket. The records of gas extraction boreholes showed that gas flow surged when 20# gas extraction boreholes, 30# gas extraction boreholes, and 76# gas extraction boreholes were 8.6m, 8.0m, and 9.1m far from the mining face, respectively. As a result, it could be concluded that the pressure-relief ranges of the N2903 mining face were 8.6m, 8.0m, and 9.1m. In combination with the numerical simulation result of COMSOL Muhiphysics, it could be obtained that the pressure-relief range of the N2903 mining face was around 8.0m.

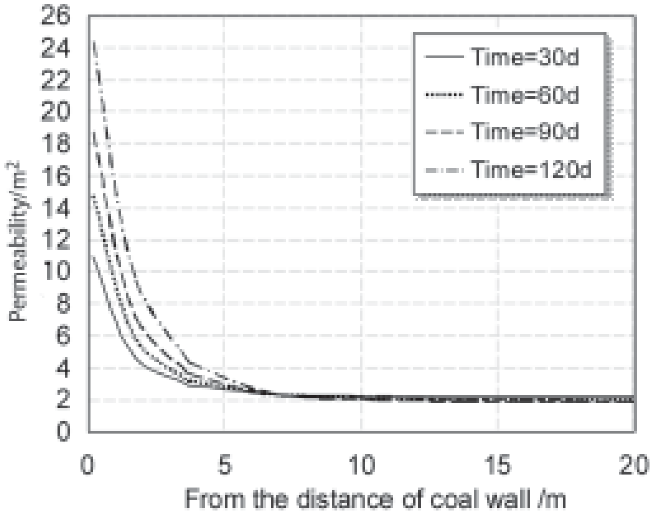


Fig.4 Curves of the permeability change

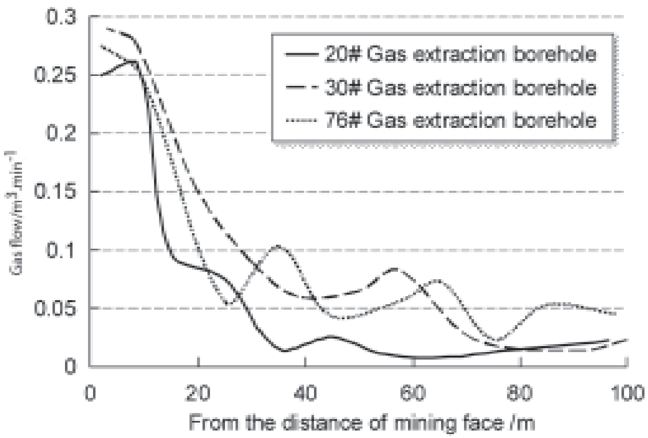


Fig.5 Curves of gas flow change

4. Determination of the reasonable number of demolished pre-drainage boreholes drilled along coal seams concerning different advancing distances of the coal mining face

In terms of determining the reasonable number of demolished pre-drilled boreholes, it is necessary to consider the comprehensive influence of the advance rate of the working face and drainage radius. According to the actual mining progress and production program, the daily advancing distance of the N2903 working face was set as 3.6m. Table 2 shows the drainage radius at different gas pre-drainage time.

(1) If the gas pre-drainage time was planned as 30d, boreholes should be installed at the drainage radius of 1.3m and the borehole space of 2.6m. Figure 6 is the corresponding borehole layout at the mining face. It could be seen that there were six pre-drilled boreholes in the pressure-relief zone that was within 8.0m from the working face. As the daily advancing distance of the N2903 working face was set as 3.6m, it was supposed to demolish 1# borehole and

TABLE 2: DRAINAGE RADIUS AT DIFFERENT DRAINAGE TIME

Drainage time/d	Drainage radius/m
30	1.30
60	1.73
90	2.04

2# borehole at the beginning; once the first advancement was completed, given that 3# borehole was only 0.3m from the working face, which was smaller than the effective drainage radius of 1.3m, 3# borehole should be demolished or else air leakage might occur during gas drainage. As 4# borehole was 1.6m from the working face, which exceeded the effective drainage radius, 4# borehole should be retained for follow-up gas extraction. All in all, on the premise that the gas pre-drainage time was 30d and that the daily advancing distance of the N2903 working face was 3.6m, the number of demolished pre-drainage boreholes was supposed to be three.

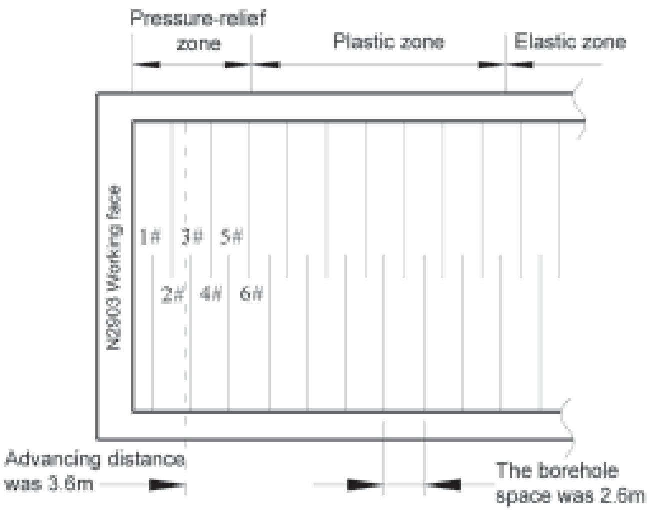


Fig.6 The borehole layout at the mining face

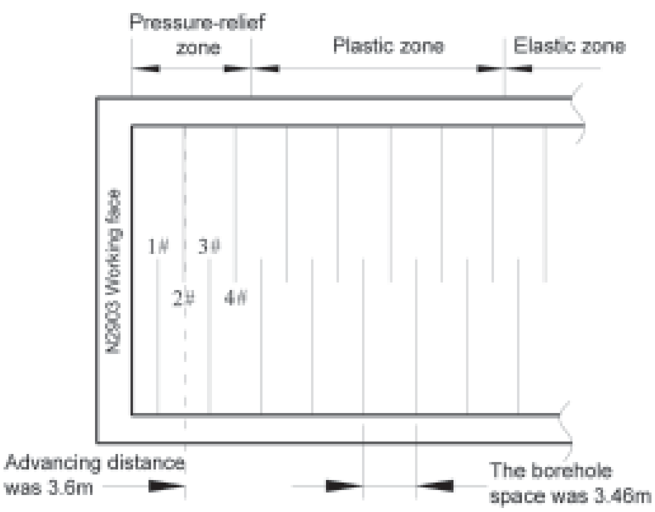


Fig.7 The borehole layout at the mining face

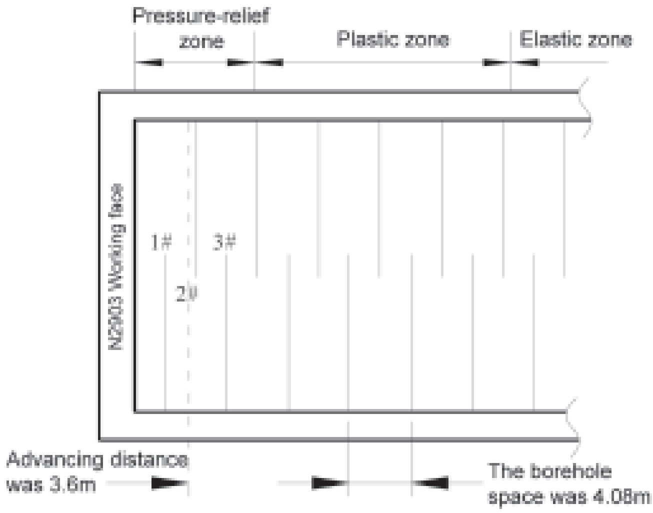


Fig.8 The borehole layout at the mining face

(2) If the gas pre-drainage time was planned as 60d, boreholes should be installed at the drainage radius of 1.73m and the borehole space of 3.46m. Figure 7 is the corresponding borehole layout at the mining face. It could be seen that there were four pre-drilled boreholes in the pressure-relief zone that was within 8.0m from the working face. As the daily advancing distance of the N2903 working face was set as 3.6m, it was supposed to demolish 1# borehole and 2# borehole at the beginning; once the first advancement was completed, given that 3# borehole was only 1.59m from the working face, which was smaller than the effective drainage radius of 1.73m, 3# borehole should be demolished or else air leakage might occur during gas drainage. As 4# borehole was 3.32m from the working face, which exceeded the effective drainage radius, 4# borehole should be retained for follow-up gas extraction. All in all, on the premise that the gas pre-drainage time was 60d and that the daily advancing distance of the N2903 working face was 3.6m, the number of demolished pre-drainage boreholes was supposed to be three.

(3) If the gas pre-drainage time was planned as 90d, boreholes should be installed at the drainage radius of 2.04m and the borehole space of 4.08m. Figure 8 is the corresponding borehole layout at the mining face. It could be seen that there were four pre-drilled boreholes in the pressure-relief zone that was within 8.0m from the working face. As the daily advancing distance of the N2903 working face was set as 3.6m, it was supposed to demolish 1# borehole at the beginning; once the first advancement was completed, given that 2# borehole was only 0.48m from the working face, which was smaller than the effective drainage radius of 2.04m, 2# borehole should be demolished or else air leakage might occur during gas drainage. As 3# borehole was 2.52m from the working face, which exceeded the effective drainage radius, 4# borehole should be retained for follow-up gas extraction. All in all, on the premise that

the gas pre-drainage time was 90d and that the daily advancing distance of the N2903 working face was 3.6m, the number of demolished pre-drainage boreholes was supposed to be two.

4. Conclusions

(1) Numerical simulation was used to study the change of stress and permeability of the coal seams in front of the N2903 mining face. According to the simulation results, within 8.0m from the coal wall, the stress state of the coal mass was smaller than the initial stress in areas, and the permeability of the coal seams that were under the pressure-relief state soared. The result demonstrated that the pressure-relief range of the coal seams in front of the mining face was 8.0m.

(2) The borehole flow method was employed to research the pressure-relief range of the coal seams in front of the N2903 mining face. Through analysis of distribution characteristics of coal seam permeability, and according to the gas flow change of 20# gas extraction boreholes, 30# gas extraction boreholes, and 76# gas extraction boreholes, it could be quantitatively judged that the pressure-relief ranges of the N2903 mining face were 8.6m, 8.0m, and 9.1m.

(3) Considering the comprehensive influence of the advance rate of the working face and drainage radius on the number of demolished pre-drilled boreholes, according to the actual mining progress and production program, it could be obtained that the number of demolished pre-drainage boreholes was supposed to be 3, 3, and 2 when the gas pre-drainage time was 30d, 60d, and 90d, respectively and when the daily advancing distance of the N2903 working face was as uniform as 3.6m.

Acknowledgment

This research is supported by Henan Key Laboratory of Biogenic Traces and Sedimentary Minerals (No. OTMP1410); Key Research Project of Higher Education Institution of Henan Province in 2015 (No. 15A440001); Dr. Funds of Henan Polytechnic University (No. B2015-05); Basic and advanced technology research projects of Henan Province (No. 162300410031).

References

1. Xie, H. P., Zhou, H. W., Xue, D. J., Zhou, H. W., Zhang, R. and Gao, F. (2012): "Research and consideration on deep coal mining and critical mining depth." *Journal of China Coal Society*, 37(4): 535-542.
2. Hou, Q. T. (2002): "Research on the technology of protecting efficiently coal and gas from gushing." *Journal of Huainan Institute of Technology*, 22(4): 11-14.
3. Liang, B., Yuan, X. P., Sun, W. J., Wang, Y. and Zhao, H. B. (2013): "Grouped pressure test to determine effective gas drainage radius." *Journal of Mining & Safety Engineering*, 30(1): 132-135.
4. Li, S. W., Zhang, Z. F. and Xuan, D. Q. (2014): "Determination on effective influence radius of in-seam borehole based on gas drainage flow method." *Coal Science and Technology*, 42(4): 43-45.
5. Zheng, L. (2015): "Determination of the gas drainage radius of low permeability and high gas coal seam by SF6 gas tracer." *Coal Geology & Exploration*, 43(3): 122-124.
6. Si, H., Tao, G. and Li, X. H. (2011): "Analysis and numerical simulation of fluid-structure coupling of gas drainage from boreholes." *Journal of Chongqing University*, 34(11): 105-110.
7. Wang, H. T., Jiang, J. J., Wang, Z. Q., Zhong, H. G. and Yuan, Z. G. (2011): "Numerical simulation of seepage field of gas extraction drilling of single bedding of mining-coal bed." *Journal of Chongqing University*, 34(4): 24-29.
8. Wu, Y. Z., Meng, L. and Jiang, Y. D. (2015): "Study on the gas flowing model containing diffusion and seepage to determine gas drainage radius." *China Mining Magazine*, 24(1): 100-103.
9. Yin, G. Z., Li, X. S., Wei, Z. A., Li, Y. J. and Wang, Q. S. (2011): "Similar simulation study of deformation and failure response features of slope and stope rocks." *Chinese Journal of Rock Mechanics and Engineering*, 30(s1): 2914-2922.
10. Li, B. (2013): Seepage characteristics of loaded coal containing gas and its application. Ph.D. dissertation, Dept. College of Resources & Safety Engineering, CUMTB. Univ., Beijing, China.
11. Wang, K., Zheng, J. Y., Xia, W., Li, P. and Li, C. (2014): "Application and study on permeability improvement effect by pressure relief in mining-induced coal body." *Coal Science and Technology*, 42(6): 65-70.