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Application research on gas drainage technology at low permeability coal seam

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ABSTRACT

Gas drainage at low gas permeability coal seams is a main barrier affecting safety and efficient production in coal mines. The research and application of drainage technology in low gas permeability coal seams is key for coal mine gas control. In order to improve the drainage effect, this paper establishes a three-dimensional solid-gas-liquid coupling numerical model and studies the gas drainage amount of different schemes inside the overburdened rock around the goaf. Yangquan mine area is chosen as the research target, and the gas movement regularity and emission characteristics are comprehensively analyzed, as well as the stress and fissure variation regularity, the scope of released gas movement, enrichment range, and movement regularity during coal extraction. Then the gas drainage technology and parameters for the current coal seam are studied. After measuring the gas drainage amount in-situ, it was found that the technology can achieve notable drainage results, where gas drainage rate increase by 30%~40% for low permeability coal seams.

KEYWORDS: gas drainage; low permeability; ground drilling holes; coupling model; abutment stress

1. INTRODUCTION

Mine gas incidents are the main disaster associated with coal mines. Mine gas extraction in China is difficult due to characteristics such as micro-porosity, low-permeability, and high adsorption of coal seams. However, coal seams in most coal mining areas belong to difficult-to-drain coal seams with low permeability, making it difficult to conduct pre-drainage as the drainage efficiency is quite low. Gas drainage in low permeability coal seams is a main barrier affecting safe and efficient production in coal mines. Therefore, the research and application of drainage technology in low gas permeability coal seams is a key technical problem in coal mine gas control.

Wang et al. (2014) studied the Klinkenberg effect of coal seams and raised an improved model. Alam et al. (2014) studied the change of permeability induced by the change of confining pressure. Wang et al. (2014) studied and utilized the drainage technology for high gas and low permeability. Guo et al. (2013) also studied methods of predicting the permeability of coal seams. Through experiments Chen et al. (2013) discussed the development of damage and permeability in coal. Other scholars have also studied coal seam permeability (Gu and Chalaturnyk, 2010; Liu and Chen et al., 2010; Liu and Rutqvist, 2010; Wang and Wei et al., 2010; Cappa and Rutqvist, 2011; Liu and Chen et al., 2011; Wang and Elsworth et al., 2011; Mitra and Harpalani et al., 2012; Pan and Connell, 2012; Aziz, 2013; Wang and Elsworth et al., 2013)

In this paper, the solid-gas-liquid coupling model will be employed to study the permeability of the coal seam in Yangquan Coal mine, and the gad drainage procedures will be addressed. At the same time, the measurements in-situ will help to test the coupling model and the drainage technology utilized in the coal mine.

2. THE SOLID-GAS-LIQUID COUPLING MODEL

2.1. The measuring method for properties of low permeability coal seam

The initial speed of methane emission($\triangle p$)is one of the predictions of risk indicators in coal and gas outburst. It can reflect the speed of coal body containing gas radiation gas and uses WT-1 gas diffusion velocity test system to measure. In addition, the competent coefficient of coal shown soundness of coal. The methane adsorption constants on coal were measured by the isothermal adsorption instrument so as to obtain adsorption constants *a* and *b*.

2.2. The analysis of gas distribution patterns by using the coupling model

Surface borehole well drawing gas is chiefly used in mining face goaf gas extraction. However, gas reservoirs and flow patterns depend on the motion features and the movement rule of overlying strata. As is well known, the moving crack of overburden can be divided into three vertical zones and cross three areas caused by mining. The three vertical zones were distributed from the bottom to the top of the caving zone, fault zone, and bending zone along the roof

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of the goaf in the vertical direction, while the cross three areas were divided into the area effected by the solid, separation area, and recompaction zone along the direction of the advancing working face. With the failure of the floor caused by mining, there were “the next three-zone”, the goaf floor from top to bottom respectively including direct damage, effect, and the small changes zone. The cracks of rock strata on the working face goaf provided space and channels for the gas reservoir and transport, and made it possible for the surface borehole well gas extraction. The changes of goaf gas flow field were analyzed by 3D model using COSFLOW simulation of the working face to the vertical stress distribution. The simulation working face was 240 m wide and 3000 m long. The mining 11.2#coal seam had an average thickness of 2.8 m and an inclination of about 13~16° on the working face. Figure 1 shows the plan of the panel. Figure 2 shows the geologic log of the model. Table 1 shows the different schemes of the model.

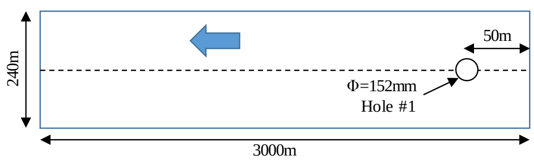

Figure 1: The plan view of the working face.

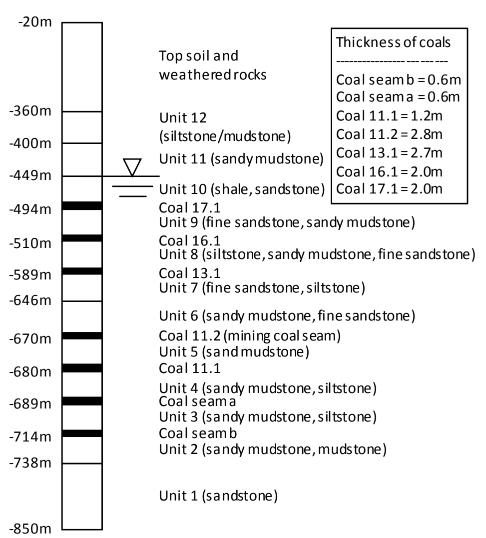

Figure 2: The geologic log of the model.

Table 1: Gas content of coal of different schemes.

Scheme	Coal 11.1	Coal 11.2	Coal 13.1	Coal 16.1	Coal 17.1
1 – 1 borehole in the goaf, low gas content in coal 11.1 and 11.2	3.84	3.84	10.4	9.6	8.0
2 – 1 borehole in the goaf, high gas content in coal 11.1 and 11.2	4.6	4.6	10.4	9.6	8.0
3 – 1 borehole in the goaf, low gas content in coal 13.1 and 16.1	4.6	4.6	9.3	9.3	8.0
4 – without borehole, high gas content in coal 11.1 and 11.2	4.6	4.6	10.4	9.6	8.0

The simulation results of panel methane emission are shown in Figure 3, in which the value of face methane emission is between 9.2-10.5 m^3/min, which approximately corresponds to the average value of methane emission of 9.6 m^3/min that is measured in the working face.

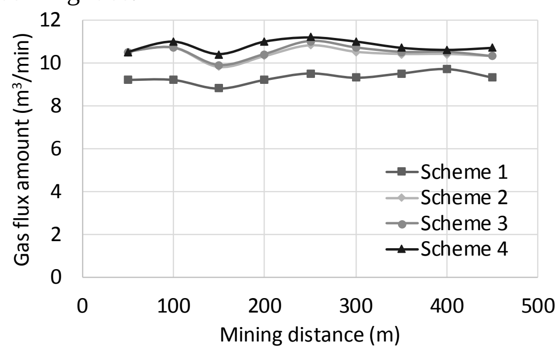

Figure 3: Comparison between the simulated and measured results.

For the specific circumstances of the measured face, the basic distribution pattern of goaf was established from a CFD model. The data which was used in the model was collected from the coal mine field, the result of COSFLOW, and the experience of the previous CFD modelling of methane flow. The basic model to the working face which was advanced 500 m from the open-off cut was used to research its goaf methane flow. The width of the basic model is 240 m, the height of the goaf fracture development zone is 100 m, the height of seam and roadways is 3.0 m, the width of all roadways is 4.0 m, the elevation of return roadways is 60 m higher than the machine roadways, and face elevation is the same with the open-off cut. Those geometric characteristics of the basic model are shown in Figure 4, which correspond with the actual situation.

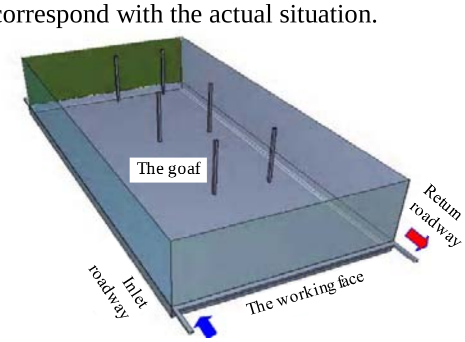

Figure 4: The numerical model.

There are two groups of ground well drilling to the goaf in the model, that is, one of the groups is along the centerline of the working face, and the other is 75 m from the return roadways. Those drillings can be opened and closed individually. The first hole is 50 m away from the working face open-off cut; the interval for the rest of the boreholes is 150 m. Table 2 provides detailed information on the modelling parameters.

Table 2: Parameters of the models.

Model parameter	Value
Working face size	length 500m/1000m, wide 240m，high 3.0m
Roadway size	wide 4m，high 3.0m ($12m^2$)
CFD model size - roof and bottom	High 100m –include segment 90m above and10m below
Seam inclination	14°
Vertical face (advance) direction & Along the face (promote) direction	Return roadways in the upper (haulage roadways above 60 m) & the left panel with the open-off cut of working face at the same level.
The ventilation system, air volume	"U" type ventilation, $35m^3/s$
Goaf gas emission quantity	The goaf 300 l/s – 400 l/s
Gas component	100% CH_4
Goaf gas drainage	along the center line of the working face and near return road (75m), the first hole is 50m away from the working face open-off cut; the interval in the rest of boreholes is 150m.

Figure 5 shows the methane distribution in the working face. It indicates that the gas concentration in the upper corner ranges between 2% to 6%, which fits the site measurements well. The figure also indicates that due to the low density of the methane, there is a small concentration at the upper part of the inlet roadway. According to the simulation, it is better to arrange the drilling holes around the inlet roadway from the surface.

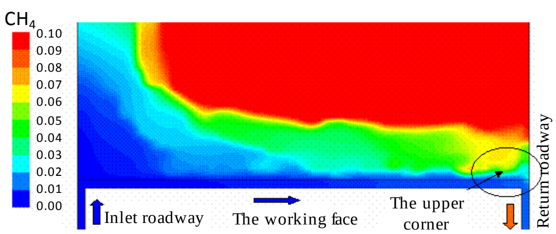

Figure 5: The methane distribution near working face.

2.3. Gas migration and emission regularity in low permeability coal seam

During the extraction, abutment pressure ahead of the working face will give the coal different degree of deformation, and coal permeability changes with this deformation, then affects the coal gas deposit and transport conditions in the coal, thus influencing the drainage effect of the coal seam gas drainage hole.

The relationship between the abutment pressure of the working face and the gas drainage amount of working face 9404 is shown in Figure 6.

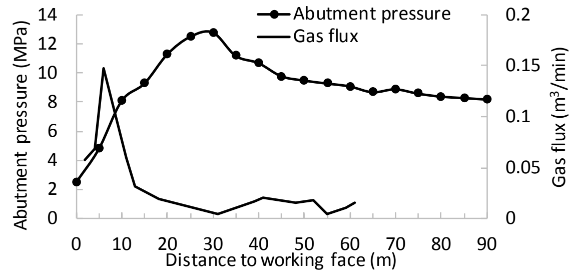

Figure 6: The relationship between the confining pressure and the gas drainage amount.

According to Figure 6, the area in front of the working face could be defined and divided into 5 zones, which are: a) zero abutment pressure and freed gas zone, where there is no abutment pressure and the gas could go through the fractures and cracks freely; b) distressed surrounding rock zone, mainly 0-10 m in front of the working face, the pressure of the surrounding rock lows, and the pressure of the coal seam lows as well, and the coal expanded due to the lower pressure, and gas has more paths to release; c) decreased abutment stress zone, which is usually 10-30 m in front of the working face, in this zone, the closer to the working face, the higher the gas emission speed; d) increased abutment stress zone, which is usually 30-60 m ahead of the working face, and with the increment of the stress, the fractures and cracks in the coal shrink and close, the permeability is lower than the original coal and as a result, the gas flux gets smaller; e) the original coal and gas area, which is more than 60 m ahead of the working face, and is barely influenced by the extraction, and the parameters of the coal and gas remain the same.

3. GAS DRAINAGE IN LOW PERMEABILITY A COAL SEAM

3.1. Gas drainage plan

Based on the numerical modelling results and the in-situ measurements, the gas drainage plan in the current coal seam is determined as follows.

The drilling holes of the current coal seam, which is perpendicular with the middle line of the transportation roadway, are drilled from the wall of the working face side. The drilling holes are separated into two vertical rows with a distance of 1.5 m, and the angles of the drilling holes are determined by the dip angle of the coal seam. Meanwhile, there are drilling holes with a 3 m distance between each other on the opposite side of the working face side. The starting drilling hole is located 18 m away from the working face in the transportation roadway and 21 m from the return roadway. All the drilling holes are 50 m long. The plan view of the drilling holes' arrangement is shown in Figure 7.

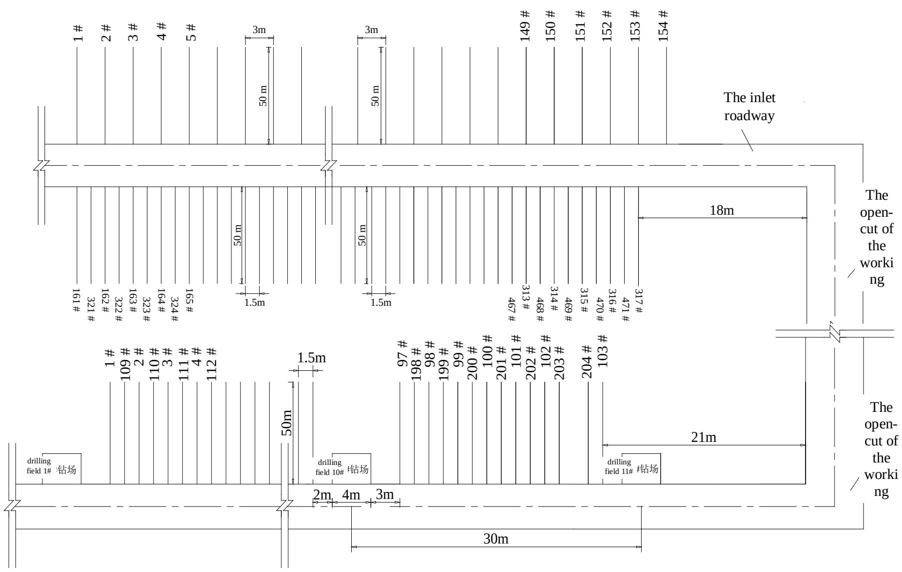

Figure 7: The layout of the drilling holes.

3.2. *The drainage effect*

The 15# coal seam is difficult to drain, and the increment of the abutment pressure during the coal extraction has a significant influence on increasing the drainage effect of the coal seam drilling holes. As shown in Figure 8, the drainage amount results through measurements could roughly be divided into four stages: I) the original drainage stage which is 40 m away from the working face; II) the weakening drainage stage, which is located between 40 m and 21.3 m away from the working face; III) the increasing drainage stage, which is located between 21.3 m and 10.3 m away from the working face; IV) the attenuate drainage stage, which is located within 10.3 m away from the working face.

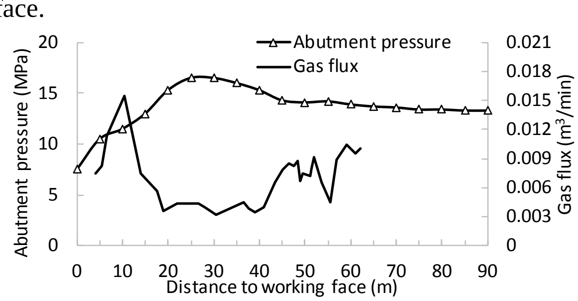

Figure 8: Relationship between confining pressure and gas drainage amount.

We can see from Figure 8 that the four drainage stages correspond to the abutment stress in front of the working face.

In stage I, the drainage amount is at a normal value, and it represents the in-situ stress before extraction. As a result, the coal is not influenced by the working face, the stress, porosity, and the storage situation of the gas are not changed, and the drainage results remain the same.

In stage II, due to the effect of the working face, there is increased abutment stress in this stage, and the pores in the coal are compressed to shrink and shut, which leads to the decrease of the coal permeability, gas flux, and gas drainage amount.

In stage III, the coal seam is located in the decreased stress zone, and the pores distribution field and the stress field are also changed, which lead to the mining-induced fractures in the coal seam. Meanwhile, the gas pressure is lowering, which causes some adsorbed gas to turn into free gas, and the gas drainage amount from the drilling holes also grows. In this stage, the gas drainage amount keeps growing and reaches a maximum value. The measurement in-situ indicates that the drainage amount of a single drilling hole is 1.88 to 5.84 times more than in stage I, with an average of 4.7, while for the drilling hole group, the drainage amount of a group is around 3.5 to 6.4 times more than a single drilling hole, with an average of 4.3.

In stage IV, though the coal seam is still located in the decreased stress area, there are too many fractures and cracks that connect to the free space of the working face and as a result, there is a lot of air pumped from the free space mixed in the drainage gas, which reduces the gas amount of the drilling holes.

4. CONCLUSIONS

This paper studies the gas drainage technology in low permeability coal seams and the main factors that affect the gas drainage with the help of theoretical analysis, numerical modelling, laboratory experiments, and in-situ measurements.

Through the measurements, the abutment pressure field, the displacement field, and the gas movement near the working face are studied, and a solid-gas-liquid coupling model is built to simulate the gas emission and the gas drainage from the ground surface.

The Yangquan coal mine gas movement and emission characteristics are studied, and the gas drainage method and key parameters of the drainage technology for the current coal seam are determined.

According to the numerical model, the arrangement of the drilling holes from the ground surface is optimized and refined. After the in-situ application, the drainage effect and the stability of the drilling holes are tested, and it indicates that the technology of gas drainage used in this paper could indeed enhance the drainage effect by 30%-40% and improve the efficiency of drainage in low permeability coal seams.

5. REFERENCES

Alam, A. K. M. B. and M. Niioka, et al. (2014). "Effects of confining pressure on the permeability of three rock types under compression." International Journal of Rock Mechanics and Mining Sciences **65**: 49-61.

Aziz, N. (2013). "Permeability and volumetric changes in coal under different test environment." Acta Geodynamica et Geomaterialia: 163-171.

Cappa, F. and J. Rutqvist (2011). "Modeling of coupled deformation and permeability evolution during fault reactivation induced by deep underground injection of CO2." International Journal of Greenhouse Gas Control **5** (2): 336-346.

Chen, H. and C. Yuan-Ping, et al. (2013). "Damage and Permeability Development in Coal During Unloading." Rock Mechanics and Rock Engineering **46** (6): 1377-1390.

Gu, F. and R. Chalaturnyk (2010). "Permeability and porosity models considering anisotropy and discontinuity of coalbeds and application in coupled simulation." Journal of Petroleum Science and Engineering **74** (3-4): 113-131.

Guo, P. and Y. Cheng (2013). "Permeability Prediction in Deep Coal Seam: A Case Study on the No. 3 Coal Seam of the Southern Qinshui Basin in China." The Scientific World Journal **2013**: 1-10.

Liu, H. and J. Rutqvist (2010). "A New Coal-Permeability Model: Internal Swelling Stress and Fracture – Matrix Interaction." Transport in Porous Media **82** (1): 157-171.

Liu, J. and Z. Chen, et al. (2010). "Linking gas-sorption induced changes in coal permeability to directional strains through a modulus reduction ratio." International Journal of Coal Geology **83** (1): 21-30.

Liu, J. and Z. Chen, et al. (2011). "Evolution of coal permeability from stress-controlled to displacement-controlled swelling conditions." Fuel **90** (10): 2987-2997.

Mitra, A. and S. Harpalani, et al. (2012). "Laboratory measurement and modeling of coal permeability with continued methane production: Part 1 – Laboratory results." Fuel **94**: 110-116.

Pan, Z. and L. D. Connell (2012). "Modelling permeability for coal reservoirs: A review of analytical models and testing data." International Journal of Coal Geology **92**: 1-44.

Wang, G. X. and X. R. Wei, et al. (2010). "Sorption-induced swelling/shrinkage and permeability of coal under stressed adsorption/desorption conditions." International Journal of Coal Geology **83** (1): 46-54.

Wang, G. and T. Ren, et al. (2014). "Improved apparent permeability models of gas flow in coal with Klinkenberg effect." Fuel **128**: 53-61.

Wang, S. and D. Elsworth, et al. (2011). "Permeability evolution in fractured coal: The roles of fracture geometry and water-content." International Journal of Coal Geology **87** (1): 13-25.

Wang, S. and D. Elsworth, et al. (2013). "Permeability evolution during progressive deformation of intact coal and implications for instability in underground coal seams." International Journal of Rock Mechanics and Mining Sciences **58**: 34-45.

Xufeng, W. and Z. Dongsheng, et al. (2014). "Methane Drainage and Utilization Technologies for High Gassy and Low Permeability Coal Seams in Tiefa Mining Area.".