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Gas migration model based on overburden strata fracture evolution law in three dimensional mine-induced stress conditions

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Abstract：Based on the fracture features obtained from similarity simulation excavation experiment in 3D mine-induced stress condition, the gas migration model in gob area was set up, and numerical simulation using COMSOL Multiphysics software on gas migration law was studied. The research results show that: Gas pressure variety gradient and flow velocity are obviously influenced by fracture distribution shape. Gas concentration distribution presents the rounded rectangle shape in the lower strata, while in higher strata it tends to be a "O shape" morphology which is similar to the fracture form in strata above the gob. Besides, the pressure relief gas mainly accumulates in the working face fracture field, especially in the higher overlying strata. In the compaction field, gas concentration distribution form presents a "saddle" shape morphology in the vertical section, and gas concentration in boundary fracture zone is higher than in the compaction zone. It is remarkable that gas concentration in start-up fractured zone is also relatively high, and with the advance of working face, its gas enrichment degree decreases. The results of the research have an important guiding significance for coal and gas simultaneous extraction.

1. Introduction

During the extraction of coal seam, the cracks, deformation, shear failure and collapse of the overburden strata caused by the pressure relief action in the gob area would lead to the occurrence of the bed-separated fissures and vertical cross-measure cracks [1-3]. The fractures network greatly increases the permeability of overlying strata, which is the main area of coal mine gas drainage. Many researchers have made plenty of research on the law of gas migration in mined-out area. Hu and Jin [4-6] regarded the gob as porous medium and used CFD software for numerical simulation to study the gob gas flow and distribution. Li[7] established a double-layered seepage flow model by studying the cave-off medium delamination and wind flow stratified flow law. Based on the simplification of the mined-out area to porous medium, Jiang[8] proposed a three-dimensional study of fully mechanized top-coal caving face with porous media hydrodynamics theory. However, due to randomness of the fracture structure and accumulation mode of the mining fractured zone, the fracture features, the scales and the continuity from the micro-point of view are no longer valid, thus the fracture structures should not be regarded as an isotropic continuous medium. Plenty of site practices have proved that the law of the methane migration in the fractured zone is quite complex, including the mechanical dispersion, floating, diffusion and the coupling of the fracture and gas flow, the overlying strata evolution law is actually a problem of the space structure evolution. The intrinsic relation between the fracture structures and the gas migration under 3D stress conditions can be more accurate to reveal the gas migration law. Hence, in this paper, firstly, the characteristics of spatial fractured fields of overlying strata are described under 3D mining stress, and then the gas migration mathematical model is established. Finally, gas migration law by using the numerical simulation method is elaborated. The gas migration law in fractured field could provide theoretical supports for the parameter optimization of pressure-relief gas drainage system.

2. Evolution law of fracture field under 3D stress condition

Under the 3D stress conditions, the rock strata will bend, shear and collapse when the working face is advanced for a certain period of time. The deformation and incongruity caused by different flexural rigidity of the strata lead to the occurrence of the bed-separated and cross-measure fractures. While the fractures in the overburden strata present a “trapezoid body” form, and the fractures in the start-up and the working face area are more developed. Furthermore, the cross-measure fractures and bed-separated fissures always interpenetrate each other. In the extension plane of coal seam, the middle area of the gob is gradually compacted away from the start-up. In the lower area of the overlying strata, the fractured zone presents a “rounded rectangle” form in the parallel plane, and with the increase of the height, the fracture distribution of the middle and high-level strata tends to be an “O-shape” form, as shown in Fig.1.

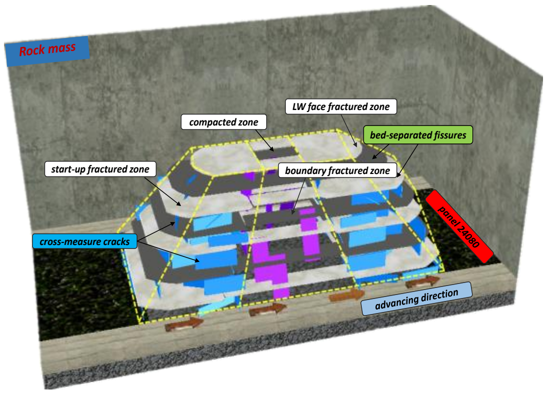


Fig.1 Three-dimensional space model of overburden strata fractured zone

3. Numerical calculation of gas migration law and analysis

Due to the random distribution of the fractures, the fracture forms and parameters are different. Because of the different properties of the rock mass and fractures, the gas flow in the gob is non-linear. In this paper, the RNG k-ε turbulence equation is adopted in the fractures. and the linear Darcy law is adopted in the rock mass. Besides, the following formula are used to deal with the interface problem between the unbroken rock and fractures, : $\mathbf{u}_{k-\varepsilon} = \mathbf{u}_{darcy}$, $P_{k-\varepsilon} = P_{darcy}$, as shown in Fig 2.

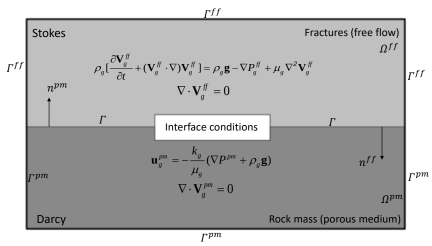


Fig.2 Schematic depiction of gob gas migration

3.1 Engineering conditions and computational model

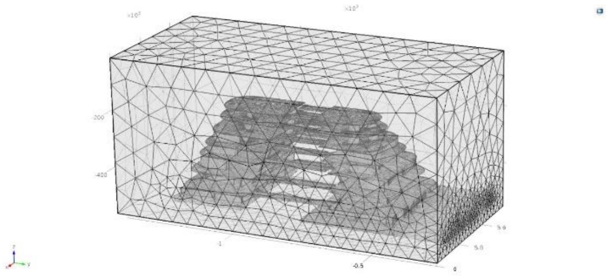


Fig.3 Mesh generation of gob fracture field

The depth of coal seam is about 900 meters, and the length and height of the working face are respectively 190m and 3.5m. Besides, the average gas pressure is 2.6MPa. Based on the results of three-dimensional excavation experiment, the key parameters such as the positions, opening sizes and lengths of fractures at different heights and longitudinal sections are statistically counted. The parameters of the physical model are as follows: The whole size of the computational model is 200m height, 100m in width and 100m length, while the heights of the caving and the fractured zones are 8m and 36m. Furthermore the mining fracture angles are separately 70° in start-up side and 64° in working face side. The gas migration law is simulated by using COMSOL Multiphysics software. Figure 3 shows the gob area model after meshing.

3.2 Methane migration and enrichment law in overlying strata

In order to study the law of gas migration and enrichment law in the overburden strata, ZXQM01-03 and QXQM01-03 planes are intercepted respectively along the strike and inclination direction of coal seam, see Figure 4. Features such as gas pressure gradient, concentration and velocity will be displayed in these planes.

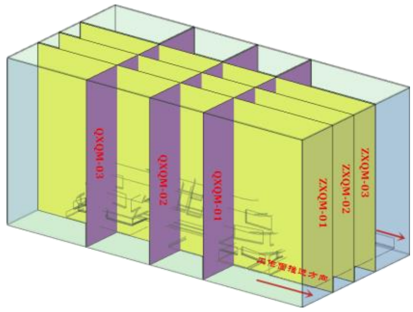
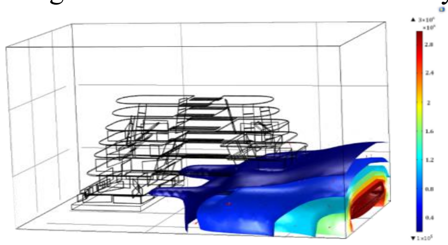
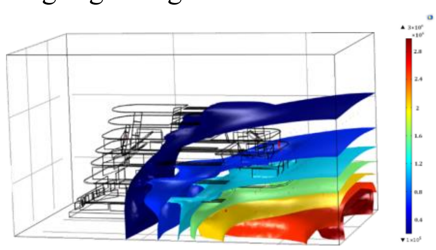


Figure 4 Cross-sections schematic diagram of inclination and strike directions

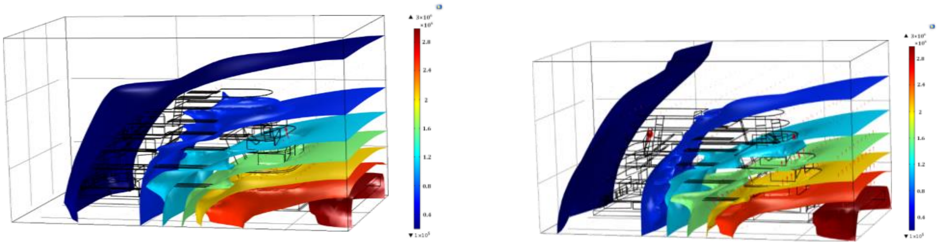
Figure 5 shows the distribution law of pressure with time in the fractured field. Figure 6 shows the gas pressure and velocity field features in the ZXJM-02 plane at t = 10000 s. We can see that both the pressure gradients and velocity are greatly affected by fracture morphology. The fractures in the working face are developed and the velocity of gas through this area is relatively large. Since the fractures are fully compacted under the action of the mine pressure, the gas is hard to flow in compacted zone. While there are still some fractures in the boundary areas near the upper and lower roadways, the gas could flow easily and the pressure gradient decreases significantly. Though plenty of fractures still exist in the start-up area, the gas pressure is smaller compared with the gas pressure nearby working face due to the far distance away from the gas gushing source.



t=1000s



t=5000s



t=9000s t=13000s

Figure.5 Features of gas pressure changing with time in fractured zones

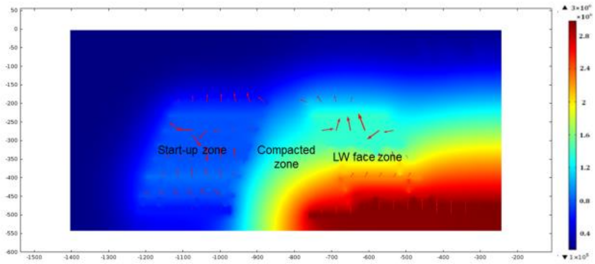


Fig.6 Gas pressure and velocity distribution at t = 10000s in ZXQM-02 plane

From the top of working face, cloud maps of the gas concentration distribution law in different height levels are drawn at t = 100000s. As shown in Fig. 7, the distribution patterns of gas concentration are in the form of a “rounded rectangle” shape in the lower strata and an “O” shape in the higher strata. This is consistent with the distribution law of the fractures in the overburden strata. While, when the gas flows from the working face to the compaction zone, most of gas flows across the cracks in the boundary area. The gas concentration distribution form in this area always presents a “□” type, and gas concentration in the boundary zone is higher than that in the compacted zone.

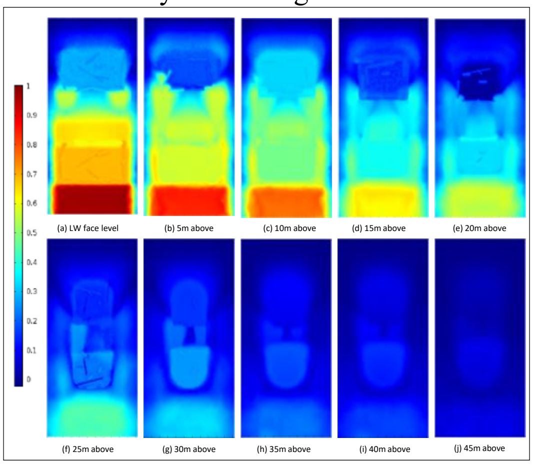


Fig. 7 Gas concentration distributions at different level planes above the LW face

Fig. 8 is the cloud maps of the velocity field features in different areas of the overburden strata. In working face fractured zone, plenty of high-pressure gas rush into the fractures, and then gradually migrate to the higher level, and the rest of gas flow through the unbroken rock as the Darcy’s pattern. In the compacted zone, the fractures are almost fully compressed by the stress, thus the gas is difficult to run through the compacted space. While cracks in the boundary fractured zone provide convenient channels for gas migration. Therefore, gas concentration distribution feature in this vertical section present a “saddle” type. In the start-up fractured zone, the gas accumulates in the bed-separated and cross-measure fractures, and the gas concentration is relatively higher.

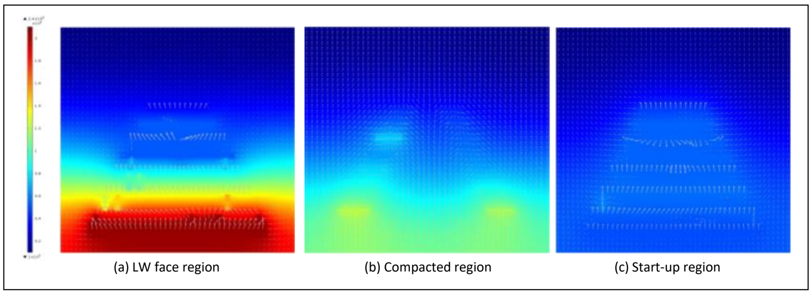


Figure 8 Methane pressure and flow distribution in different fractured zones above gob

4 Conclusions

(1) The gas pressure gradient and velocity field are greatly affected by the fractures. Both the gas pressure and velocity are higher in the working face fractured zone. Then, in the compacted zone, the fissures are fully compacted with the action of the mine pressure, thus the gas is more difficult to flow across this area. Though plenty of fractures still exist in the start-up area, the gas pressure is smaller compared with the gas pressure nearby working face due to the far distance away from the gas gushing source.

(2) The distribution law of gas concentration presents respectively a “rounded rectangle” and an “O-shape” in the lower and higher strata, which is consistent with the fractures distribution law in the overburden strata.

(3) The pressure relief gas is mainly gathered in the working face fractured zone, boundary fractured zone and start-up fractured zone, and the gas concentration gradually decreases with the increase of height. Besides, with the advance of the working face, the degree of gas enrichment in start-up fractured zone is gradually reduced.

Acknowledgments

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