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# Numerical Simulation Study on Gas Distribution Law in Goaf of Thick Coal Seam Mining Face

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## Abstract

**To study the gas distribution law in the goaf of low-permeability and extra-thick coal seam comprehensive mining working face, Fluent simulation software is used to numerically simulate the gas distribution law of the goaf in the east 102 working face of the mine. The results show that under the comprehensive mining conditions of the U-shaped upwind ventilation working face, the high concentration gas in the deep part of the goaf accumulates on the return air side, forming a gas-rich area, with the highest gas concentration reaching 70%. The simulation results are basically consistent with the field measurement data, providing important theoretical support for the implementation of gas extraction measures in the goaf.**

## Keywords

**Goaf Area, Comprehensive Mining, Gas Distribution, Numerical Simulation.**

## 1. Introduction

The gas in the mining coal face mainly comes from goaf and adjacent layers, with more than 50% of the gas emission in the goaf [1]. In some low-permeability and high-gas thick coal seams, the gas emission in the goaf during comprehensive exploitation accounts for about 70% of the gas volume in the working face space [2,3]. Therefore, it is of great importance to study the gas distribution and flow law in the goaf of low-permeability and high-gas thick coal seams during comprehensive exploitation, which has very important guiding significance for the implementation of gas drainage control measures in the goaf[4,5].

The mine in Gansu belongs to a coal and gas outburst mine, with coal seam gas content ranging from 9.22m$^3$/t to 10.17m$^3$/t, and the maximum gas pressure of 1.88MPa. The East 102 working face is located in the original coal seam of the East 1 mining area, and during the mining period, gas exceeding the limits has occurred multiple times, with one large gas outburst reaching 4000m3/min, seriously affecting the normal mining of the working face. In order to improve the gas extraction rate in the goaf, it is necessary to accurately grasp the distribution and migration characteristics of gas in the goaf. Domestic scholars have conducted extensive research on the distribution and extraction laws of gas in thin coal goafs, with less research on low permeability extremely thick coal goafs. This study takes the East 102 fully mechanized caving face of a mine in Gansu as the research object, conducts real-time monitoring in the goaf by setting up bundle tube monitoring sampling points, and uses fluent simulation software to compare and analyze the distribution laws of gas in low permeability extremely thick coal goafs, which is of great significance for the implementation of gas extraction measures in goafs and the improvement of gas extraction rates[6,7].

ISSN: 2710-0588

## 2. Study on the Theory of Gas Migration in Goaf Areas

Assuming the goaf of the coal mining face towards the long wall is a porous medium, take a tiny unit volume in the goaf as the control volume. The coordinates of its center $C$ are ($x$, $y$, $z$), with side lengths of dx, dy, dz. The instantaneous velocity components passing through point $C$ are $u_x$, $u_y$ and $u_z$, with a density of $\rho$.

Assuming that there are source and sink terms with intensities $W_g$ and $W_s$ inside the control volume, mainly representing the gas amount released from the coal body and the gas amount extracted at the extraction point. To calculate the fluid mass change in each control volume, it is necessary to calculate the fluid mass passing through the control volume surface[8].

The mass difference of gas inflow and outflow within the time $dt$ in the control body is:

$$dM = dM_x + dM_y + dM_z = [\frac{\partial(\rho u_x)}{\partial x} + \frac{\partial(\rho u_y)}{\partial y} + \frac{\partial(\rho u_z)}{\partial z}]\varphi dxdydzdt \tag{1}$$

Under the action of $W_g$ source term, the mass of gas entering the control volume in time $dt$ is:

$$dM_{wg} = W_g ndxdydzdt \tag{2}$$

Under the influence of the $W_s$ term, the mass of gas flowing out of the control body within the time dt is:

$$dM_{ws} = W_s ndxdydzdt \tag{3}$$

According to the law of conservation of mass, we have:

$$dM + dM_{wg} - dM_{ws} = 0 \tag{4}$$

Equation (1) to (3) substituted into equation (4) gives the system of continuous equations:

$$\frac{\partial(\rho u_x)}{\partial x} + \frac{\partial(\rho u_y)}{\partial y} + \frac{\partial(\rho u_z)}{\partial z} + W_g - W_s = 0$$

That is: $div(\rho u_i) + \rho_{CH4} w_g - \rho_{CH4} w_s = 0$

In the equation: $\rho_{CH4}$ , $W_g$ and $W_s$ represent gas density, the volume of gas released from unit volume of coal per unit of time, and the amount of gas extracted, respectively.

## 3. Gas Distribution Law Simulation in Goaf Area

### 3.1. Overview of the Work Area

The 102 working face in the east of a mine in Gansu is the first mining face in the eastern mining area, located in the unmined 1# coal seam. The strike length of the working face is 920m, the dip length is 150m, the average mining thickness of the coal seam is 17.5m, with a locally maximum coal thickness of 42m, interbedded with 1-7 layers of gangue with a thickness of 0.3-0.7m, and the structure is complex. The original gas content of the coal seam is 10.17m$^3$/t, the

ISSN: 2710-0588

maximum gas pressure is 1.88 MPa, the coal strength coefficient is 0.31, the coal seam permeability coefficient is $2.13\times10^{-3}m^3/atm^{-2}d$, belonging to low permeability coal seam. Despite the arrangement of in-seam boreholes during roadway development for gas drainage while mining, the residual gas content at the working face still reaches $8.23m^3/t$, which does not meet the requirement of the "Coal Mine Safety Regulations" for the gas content at the working face to be below $6m^3/t$ during mining. The working face adopts the U-shape ventilation method with an air volume of $2000m^3/min$, and a high-level gas drainage roadway is arranged for gas drainage in the goaf, using a once-through fully mechanized coal mining method to extract the top coal.

## 3.2. Establishment of Mining Face Geometric Model

The length of the geometric model is 400m, the width is 135m, and the height of the fissures in the goaf is 120m. The roadway width of the transportation haulage and return airway is 4m, the height is 3m, and the length is 30m. The position of the intake of the transportation haulage is set as the coordinate origin (0,0,0) point. The goaf extends along the *X*-axis, inclines along the *Y*-axis, and vertically along the *Z*-axis. See specific parameters in Table1.

**Table 1.** Basic parameters of CFD model simulation for 102 East working face.

| Model parameter | Parameter value |
|---|---|
| Working face dimensions | Length 400m, width 135m, height 120m |
| Tunnel dimensions | Width 4m, height 3.0m ($12m^2$) |
| CFD model dimensions | Height 120m |
| Ventilation method | "U" shape ventilation |
| Gas composition | 100% |
| Methane drainage in goaf | None |

According to the actual layout of the mine, the CFD model of the eastern 102 working face is constructed and meshed with hexahedrons through Fluent's Gambit preprocessor, with approximately 500,000 cells, as shown in Figure 1. Figure 1 shows the mesh division of the CFD model for gas flow in the longwall working face.

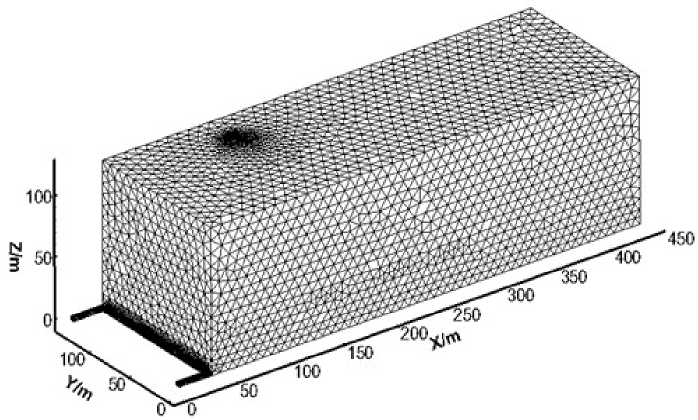


**Figure 1.** Geometry model and grid diagram of goaf area

## 3.3. Numerical Simulation of Gas Distribution in Goaf Area

The gas components in the goaf mainly include: $CH_4$, $O_2$, $CO_2$, CO, etc. This paper mainly studies the distribution law of $CH_4$, and the three-dimensional distribution map is shown in Figure 2.

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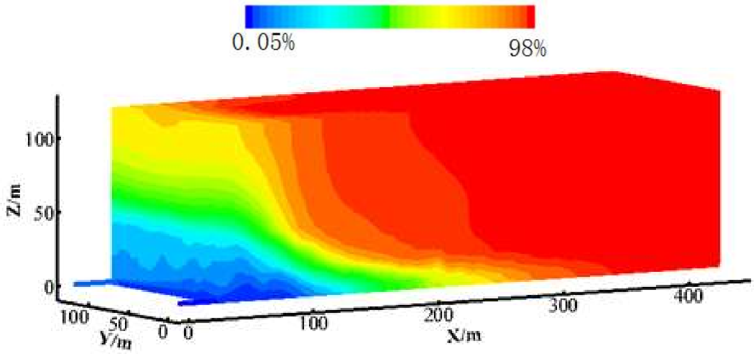
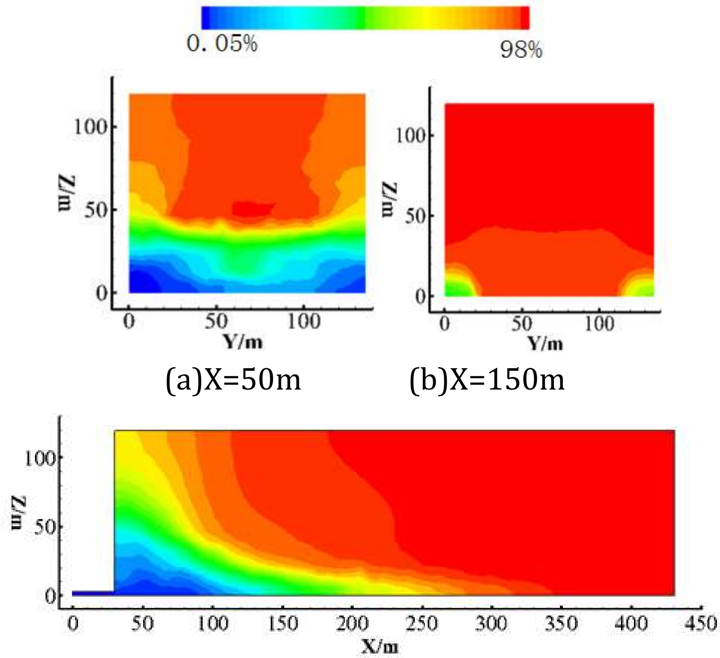



**Figure 2.** The 3D distribution map of methane in goaf area.

According to Figure 2, it can be seen that the goaf air leakage zone, i.e., the area near the working face and the original intake and return air roadways, has a low gas concentration. This is mainly due to the fact that the original intake and return air roadways in the goaf were not adequately sealed off during the mining process, causing the roof not to collapse, and the working face support is good, resulting in a high permeability and strong air leakage near the working face, leading to gas dilution and low concentration. As it extends towards the deeper part of the goaf, the roof collapses completely, becomes compacted, with low permeability, and there is no air leakage flow diluting the gas, plus a large amount of released gas, leading to a higher concentration.

Due to the formation of vertical three zones in the goaf during coal seam mining and the characteristics of gas itself, the gas concentration from the floor to the area where fractures develop gradually increases. The gas concentration gradient varies greatly between the re-compacted zone and the developed fracture zone, but the gas concentration gradually stabilizes in the upper part of the developed fracture zone with little change. Refer to Figure 3 for details.




(a)X=50m (b)X=150m

(c)Y=0m

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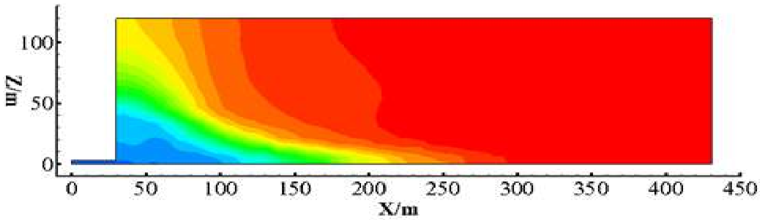
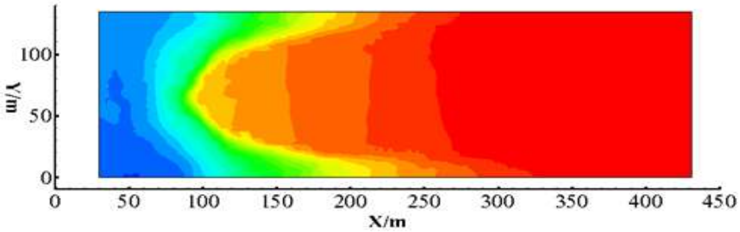
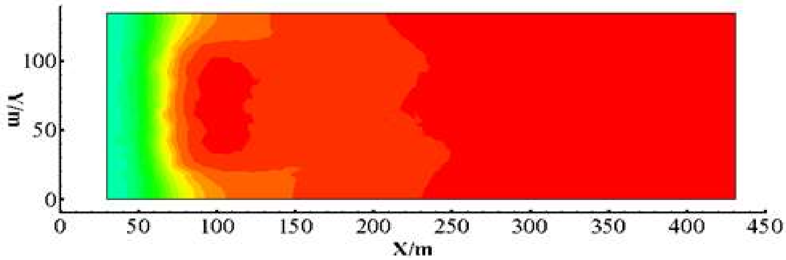



(d)Y=135m




(e)Z=10m




(f)Z=50m

**Figure 3.** Distribution of gas volume fraction in different sections

Figure 2 and 3 show the distribution pattern of gas concentration in the goaf area of the working face. From the figures, it can be seen that:

(1)Gas distribution rules in mining areas

The goaf near the working face area has a low gas concentration, which is the blue area in the figure, mainly because the rock in this area is in the initial collapse state, the ventilation air in and return air out of the goaf during the mining process is not sufficient, the support is good, the roof has not completely collapsed. Generally, dozens of meters of uncollapsed or partially collapsed goaf will form behind the upper corner and lower corner, and the air leakage flow will enter the goaf from the lower corner under the negative pressure of ventilation, diluting the gas and carrying it out from the upper corner of the working face. Therefore, the greater the air leakage flow speed near the working face area in the goaf, the greater the impact on the dilution and transportation of gas, while in the deeper part of the goaf, due to the rock's re-compaction and the smaller impact of the air leakage flow, the effective channels become smaller and smaller, making it difficult for most gases to enter the compacted center of the goaf.

The methane concentration in the goaf area gradually increases from the floor to the fracture zone area, especially in the goaf and fracture zone transition zone, where the methane concentration gradient changes significantly. However, the methane concentration in the upper part of the fracture zone tends to be stable, with little gradient change. The main reason for this phenomenon is the upwelling and convection diffusion of methane, as well as the development of fractures in the overlying strata, leading to the accumulation of a large amount of methane in the upper area of the fracture zone.

(2) Distribution law of gas inclination

The methane concentration gradually increases from the bottom outlet to the top outlet of the working face, as shown in Figure 3(e). In the area from the bottom outlet to the middle, a part

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of the methane released by coal wall desorption enters the goaf through air leakage, resulting in a small change in methane concentration in the working face. However, in the section from the middle to the top outlet, the methane concentration is higher due to the methane carried out by the air leakage in the goaf and the methane released by coal wall desorption, especially at the upper corner where gas accumulation is more likely to occur.

The deep area of the goaf shows a trend of increasing gas concentration from the intake air side to the return air side, as shown in Figures 3(e) and 3(f). This is mainly because the original intake and return airways in the goaf have not collapsed or only partially collapsed, creating several tens of meters of voids. The leakage airflow can easily enter the incompletely collapsed voids from the lower corner, diluting the gas. Meanwhile, under the negative pressure of ventilation, some high-concentration gas flows out from the upper corner of the void formed by the original return airway, causing a decrease in gas concentration in this area.

(3) The law of gas distribution towards the upper side.

As the goaf extends deeper, the gas concentration shows a gradually increasing trend, as shown in Figures 3(c) and 3(d). This is mainly because as the goaf extends deeper, the influence of ventilation negative pressure decreases, the chance of ventilation diluting the gas concentration decreases, the probability of gas being taken out by the goaf decreases, and the regional gas concentration becomes higher.

(4) The vertical distribution pattern of gas.

From Figure 3(e) and Figure 3(f), it can be seen that the distribution of gas at different heights in the $z$-plane shows that the gas concentration at higher levels is higher than that at lower levels. This is mainly due to the formation of vertical three-stripes and the physical characteristics of gas in goaf, as well as the effect of leaking air in the air leakage zone. The higher the goaf gas is, the less it is affected by leaking air, the easier it is to accumulate, and the closer it is to the return air side, the higher the gas concentration. This is also the main reason for the high gas concentration in the fracture zone as shown in Figure 3(d).

## 4. Conclusion

(1)The Fluent simulation of the low-permeability and ultra-thick coal seam goaf gas distribution patterns is in basic agreement with the on-site borehole monitoring results, therefore, the Fluent simulation provides a feasible means for studying and analyzing the gas distribution patterns in the goaf.

(2)The simulation results of the fluent software show that in the low-permeability ultra-thick coal seam comprehensive mining, the goaf area extends to the deep, the higher the gas concentration, the higher the gas concentration on the return air side, and the deep return air side is the gas enrichment area, with the highest gas concentration reaching 70%.

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