

Gas Emergence Characteristics of the Upper Corner on the 215101 Mining Working Face of the Yue Nan Coal Mine

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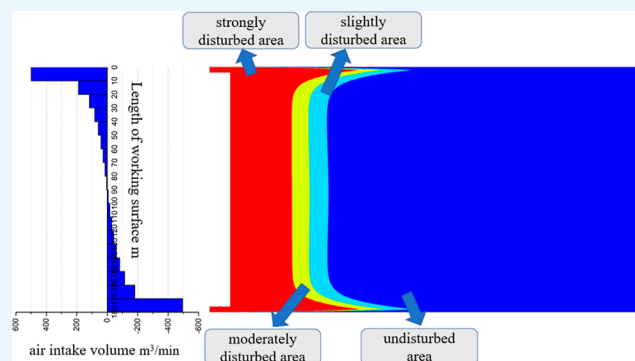
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ABSTRACT: To prevent the gas over limit in the upper corner of the 215101 working face of the Yue Nan coal mine, a numerical simulation method was used to analyze the gas concentration in the upper corner of the working face at different air intake volumes and mining velocities. The research results show that the gas concentration in the upper corner is 0.78, 0.52, 0.39, and 0.32% when the wind speed of the intake airflow roadway is 1, 1.5, 2, and 2.5 m/s, respectively, and an optimal wind speed of the intake airflow roadway is selected as 2 m/s. When the wind speed of the intake airflow roadway is 2 m/s, the working face mining velocity is 1, 2, 3, and 4 m/d, and the gas concentration in the upper corner is 0.27, 0.39, 0.58, and 0.83%, respectively, and an optimal working face mining velocity of 3 m/d is selected. Under the optimal mining conditions, the working face wind leakage area is divided, with 0–30 m of the working face as the main leakage area and 150–180 m as the wind flow compensation area. According to the wind speed in the gob, the wind flow disturbance area is divided, the gob 0–50 m is the wind flow intense disturbance area, which is the main area of the upper corner gas source; the gob 50–62 m is the wind flow medium disturbance area, which is the secondary area of the upper corner gas source; the gob 62–75 m is the slight disturbance area, which has less influence on the upper corner gas concentration; the gob after 75 m is the wind flow undisturbed area, and the upper corner gas concentration is almost unaffected by it.



1. INTRODUCTION

China's coal seam geological conditions are complex; production conditions are poor, and there are many kinds of disasters; gas disasters and mine fires are the main disasters that affect coal mine safety,^{1–4} and gas aggregation and overlimit at the working face are necessary conditions that cause gas disasters in coal mines. China's well mining operations are mainly long-wall mining. Most of the working face is U-shaped ventilation; wind flows from the intake airflow roadway into the mining working face; a part of the wind flows over the working face, through the return airflow roadway; another part of the wind flows into the gob, resulting in the accumulation of gas in the gob, and a part of the wind flows after mass exchange from the upper corner and gushes out, resulting in the upper corner gas over limit.⁵ Once the gas in the upper corner exceeds the limit, it may lead to spontaneous gas combustion, gas explosion, and other mine disaster accidents, which is a serious threat to the safe operation of the underground.

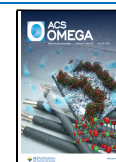
A large number of scholars have conducted a lot of research on the management and prevention of mine gas disasters and mine fires. The exchange of the wind flow between the working face and the gob is one of the main reasons for the occurrence of two kinds of disasters, so the study of the amount of the air intake in the working face and the ventilation is essential. Wang et al.

used numerical simulation software and a self-built experimental platform to simulate the influence of different air intake volumes on the upper corner on the working face and the gas distribution in the gob and summarized the gas concentration distribution law by analyzing the simulation results: the larger the air intake volume, the lower the gas concentration in the upper corner on the working face; different air intake volumes have different effects on different locations in the gob, and the shallow part of the gob is more affected by the wind speed, while the deep part of the gob is almost not affected by the wind speed. Some scholars believe that the change of the ventilation mode will lead to the change of gas distribution in the gob through numerical simulations^{6,9–13} and field measurements¹⁴ compared with U-type, U + L-type, Y-type, and Y + L-type ventilations, and through a comparison, they found that Y-type and U + L-type ventilations can effectively manage the upper corner gas over

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limit problem; at the same time, the change of the ventilation mode brings some problems; Y-type ventilation leakage compared with the U-type ventilation leakage area is larger; the gob oxidation warming zone range is wider; as the U + L digging volume increases, it will cause workload increase and mining relationship imbalance. Zheng et al.^{15–17} conducted similar simulation experiments through a self-built experimental platform to simulate the effect of the presence or absence of a heat source on the gas concentration in the gob and concluded that the magnitude of gas concentration variation in the gob decreases with increasing distance from the high-temperature point vertically based on the measured point data, proving that temperature is the main factor affecting the change in gas concentration and gas accumulation in the gob.

In order to ensure safe and efficient mining, it is of utmost importance to study how to manage the gas over limit in the upper corner of the working face. The gas over limit in the upper corner of the gob is caused by the air leakage from the working face carrying out the gas in the gob, so the study of the air leakage from the working face and the gas distribution in the gob is necessary to prevent the gas over limit in the upper corner. Chen et al.^{18,19} analyzed the wind flow transport characteristics by numerical simulations and similar simulation experiments, and the study showed that the larger the amount of wind leakage into the gob, the greater the explosion potential of the gob. Therefore, the air leakage area of the working face and the contact surface of the gob is divided, and the air leakage area is protected against wind leakage to effectively prevent the occurrence of spontaneous combustion of coal left in the gob. Wang et al.²⁰ measured the gas concentration at different locations of the gob by arranging measurement points in the field, analyzed the gas distribution law in the gob according to the measurement results, and explored the gas gushing mechanism in the gob. Through gas extraction in the gob, the gas concentration in the gob can be reduced, which can effectively prevent the gas over limit in the upper corner of the working face. In order to prevent the upper corner gas over limit, some scholars have analyzed the upper corner gas concentration and the gas concentration in the gob on the working face under different extraction positions,^{21,22} extraction volumes,^{23,24} and extraction angles²⁵ through numerical simulations^{26,27} and field measurements²⁸ and selected the optimal extraction position and compared the upper corner gas concentration and the gas concentration in the gob before and after extraction, which proved that the extraction can better solve the problem of gas over limit in the upper corner of the working face and has a significant effect on the gas management in the gob. From the above research, it can be seen that the results obtained by field measurements and the results obtained using numerical simulation software are in good agreement for mine gas research.

The above studies, whether numerical simulations or similar simulated experiments, have conducted useful exploratory studies on the gas gushing characteristics of the upper corner of the gob and working face according to different actual working conditions and geological conditions. However, some scholars have only studied the wind flow, or most of the gas studies have analyzed the gas gushing characteristics of the gob, while the analysis of the gas gushing characteristics of the upper corner is not clear enough. Therefore, in this paper, on the basis of previous research, using FLUENT software to simulate the effect of different inlet air volumes and working face advancement speeds on the gas gushing from the upper corner of the 215101 back mining workings, we compare the simulation

results and select the air intake volume and mining velocity for the Yue Nan coal mine to ensure that mining is carried out safely and efficiently. In addition, we also study the effect of the wind flow and gas transport in different areas of the gob on the gas gushing out from the upper corner under such conditions and verify the simulation results by measuring the gas concentration in the upper corner and return airflow roadway during the actual mining process so as to provide some theoretical reference for the working face under similar mining conditions.

2. MODEL CONSTRUCTION AND MESHING

2.1. Overview of the Experimental Mine. The Yue Nan coal mine is located in Dananzhuang village, 26 km northwest of Jincheng City, Shanxi Province. The mine is a high gas mine with a maximum absolute gas gush of 19.06 m³/min and a maximum relative gas gush of 7.55 m³/t. The well field covers an area of 11.6582 km²; the strata are generally gentle, with dip angles between 2 and 7°, generally around 4°, and the no. 15 coal seam is currently being mined. The mine is arranged with one comprehensive mining once mining full height working face, equipped with two comprehensive mechanized digging working faces, with a production capacity of 1.2 million tons/year.

The gas content of the no. 15 coal seam in the Yue Nan coal mine is high in the northwest and low in the southeast; the maximum gas content is 5.68 m³/t in the first gob, 4.61 m³/t in the second gob, and 7.46 m³/t in the third gob. The coal seam thickness is 2.89–4.51 m, with an average of 3.26 m; the stopping line is 50 m east of the wind tunnel; the strike length is 516 m in the stopping line, and the length of the open cut is 180 m. The average thickness of the coal seam is 3.26 m, which generally contains 0–4 layers of gangue, and the structure of the coal seam is simple. The lithology of the top plate of the coal seam is K2 tuff; the lithology of the bottom plate is mudstone, aluminous mudstone, and sandy mudstone. The upper distance from the no. 9 coal seam is 34.02 m; the thickness of the coal seam is 3.26 m, and the structure of the coal seam is simple-complex, and it is a stable area-wide mineable coal seam; the distance from the no. 13 coal seam is 14.78 m, and the thickness of the coal seam is 0.38 m, and it is an unmineable coal seam. The coal seam column diagram is shown in Figure 1.

The gas gushing out from the working face mainly consists of coal relic gas gushing out from the gob, gas gushing out from the











Level number	Rock stratum name	Column distribution	Burial depth(m)	Layer thickness(m)
8	Sandy mudstone		447.08	20.05
9	9# Coal seam		448.11	1.02
10	Sandy mudstone		455.88	7.77
11	Siltstone		466.97	11.09
12	13# Coal seam		467.35	0.38
13	Sandy mudstone		472.69	5.34
14	Limestone		481.82	9.13
15	Mudstone		482.13	0.31
16	15# Coal seam		486.13	4.00
17	Mudstone		490.82	4.69

Figure 1. Integrated bar chart.

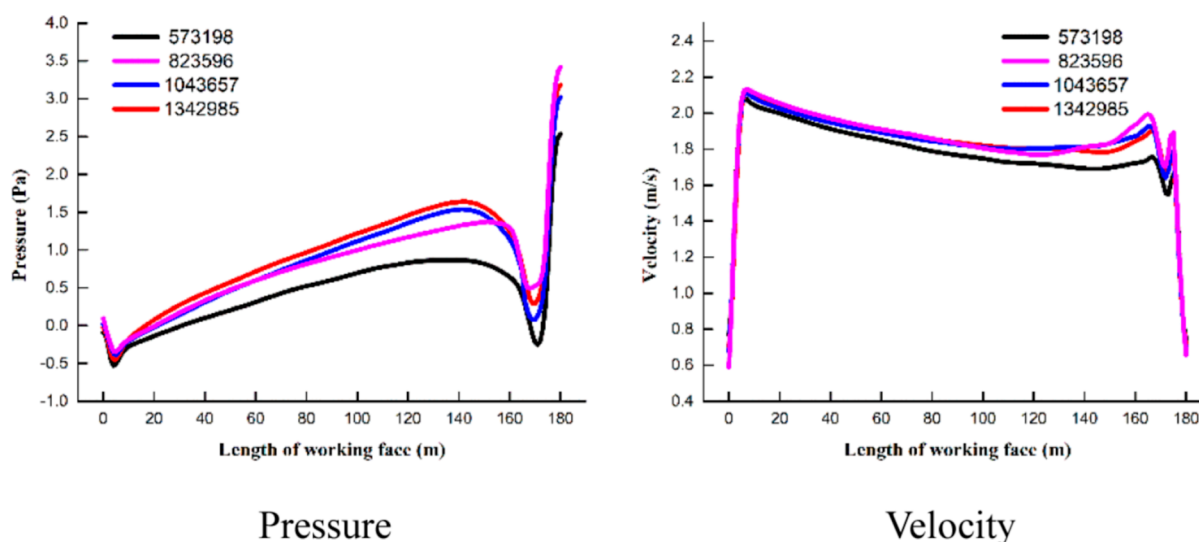


Figure 2. Changes of interface parameters with different mesh numbers.

neighboring layer, and gas gushing out from the neighboring working face, and the gas gushing out is calculated according to the method of predicting the gas gushing out from separate sources, and the maximum absolute gas gushing out from the working face is $6.17 \text{ m}^3/\text{min}$; the gas gushing out from the neighboring layer is $2.41 \text{ m}^3/\text{min}$; the gas gushing out from the neighboring working face is $3.24 \text{ m}^3/\text{min}$, and the total gas outflow is $11.84 \text{ m}^3/\text{min}$.

2.2. Mathematical Modeling of the Gob. The wind flow in the gob follows the law of conservation of mass and the law of momentum equations in the three-dimensional (3D) model.

Equation of mass conservation

$$\frac{\partial p}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (1)$$

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (2)$$

$$\frac{\partial(nu)}{\partial x} + \frac{\partial(nv)}{\partial y} + \frac{\partial(nw)}{\partial z} = 0 \quad (3)$$

where ρ is the density of the fluid in porous media, kg/m^3 ; t is the time, s ; n is the porosity, a dimensionless coefficient; and u , v , and w are the vector components of the fluid along the x , y , and z coordinate axes, respectively.

Momentum equations

$$\begin{aligned} & \frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} \\ &= \frac{\partial}{\partial x} \left(\mu \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left(\mu \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z} \left(\mu \frac{\partial u}{\partial z} \right) - \frac{\partial p}{\partial x} + S_x \end{aligned} \quad (4)$$

where p is the pressure acting on the surface of the microelement of the porous medium, Pa ; ρ is the density of the fluid, kg/m^3 ; t is the time, s ; μ is the aerodynamic viscosity in the porous medium, $\text{Pa}\cdot\text{s}$; and S_x is the generalized source term of the fluid in the flow process, respectively.

2.3. Assumptions for the Construction of the Physical Model of the Gob. In the actual mining process, the environment of the gob is very complex, so for the purpose of

analysis, idealized assumptions are made for the working face, the roadway, and the gob. The specific assumptions are as follows.

- (1) The gob is treated as homogeneous for each multi-air medium, and the inlet and return roadways, working face, and gob are considered as hexahedra for physical modeling.
- (2) It is assumed that the gas mixture consisting of air and gas inside the gob is an incompressible ideal gas.
- (3) The simulation process does not consider the effect of temperature, humidity, pressure, and other factors on gas.
- (4) Assume that only gas gushes out from the gob, and no chemical reaction occurs between the gas components.
- (5) Assume that the gas in the fracture zone is uniformly distributed.
- (6) The coal seam dip angle is small, and it is assumed that the coal seam is horizontal.
- (7) Assume that the wind flow is turbulent in the inlet and outlet alleys and working face, and the wind flow inside the gob is laminar flow.

2.4. Physical Model Construction and Meshing of the Gob. The average mining height of the 215101 working face of the Yue Nan coal mine is 3.26 m , and the height of the fallout zone in the gob is calculated according to the following empirical formula.

$$h_m = \frac{m}{(k_p - 1)\cos \alpha} \quad (5)$$

$$h_l = \frac{100m}{1.6m + 3.6} \pm 5.6 \quad (6)$$

where m is the thickness of the mined coal seam, m ; k_p is the rock fragmentation and swelling characteristics, a dimensionless coefficient; and α is the dip angle of the coal seam, $^\circ$.

The physical model is constructed according to the actual size of the gob of the 215101 working face of the Yue Nan coal mine, with a strike length of 300 m , a tendency length of 180 m , an average mining height of 3.26 m , a caving band height of about 15 m according to eq 5, and a slit band height of about 30 m according to eq 6. The working face adopts a U-shaped ventilation system; the length of the intake and return airflow

roadway is 20 m, the width is 4 m, and the height is 4 m, and the length of the working face is 180 m, the width is 5 m, and the height is 4 m.

Different grid sizes were set to divide the physical model, and four grid quantities were divided into physical models with grid quantities of 573198, 823596, 1043657, and 1342985, and the average grid quality was above 0.95. The four grid quantities were tested for irrelevance, and the pressure and velocity measurement lines were set in the center of the working face, and the results of the preliminary simulation under the same conditions are shown in Figure 2.

As can be seen from Figure 2, after the number of grids exceeds 1043657, the pressure and velocity distributions of the working face in the simulation results are less affected by the number of grids, and the calculation results tend to be stable after the number of grids increases to a certain degree; taking into account the calculation time and numerical simulation errors, the grid size of the inlet and return airflow roadway and working face is set to 0.5 m; the grid size of the caving band is 1 m, and the grid size of the slit band is 2 m, and a total of 1043657 grids and 1129165 nodes. The physical model and grid division of the gob are shown in Figure 3.

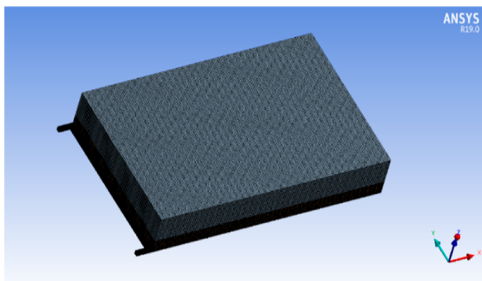


Figure 3. Physical model and meshing of the gob.

3. MODEL OF GAS RELEASE AND TRANSPORT IN THE GOB

3.1. Permeability Distribution Pattern in the Gob. The porosity distribution in the U-shaped ventilated gob is in accordance with the “O”-shaped circle distribution law.^{29,30} Along the strike direction, as the distance increases from the working face, the smaller the porosity of the gob, which finally tends to stabilize; along the tendency direction, due to the influence of the cantilever beam structure, the porosity is larger at the location of the incoming and outgoing wind tunnels in the gob, and the porosity gradually decreases from both sides of the gob to the middle and finally tends to stabilize; along the vertical direction, the porosity gradually increases from the bottom to the top of the gob.

We take the bottom of the intersection interface between the retrieval working face and the gob as the coordinate origin and set the direction extending deeper into the gob as the positive direction of the x -axis and the upward direction along the retrieval working face as the positive direction of the y -axis. According to theoretical and field experience analyses, the porosity in the gob and the working face distance relationship is shown in eq 7.

$$n_x = 0.2e^{-0.0223x} + 0.1 \quad (7)$$

where n_x is the porosity of the gob along the x -axis direction and x is the coordinate value of the x -axis at a point in the gob, m.

The porosity variation coefficient along the y -axis direction is related to the y -axis coordinate value as shown in eq 8.

$$n_y = \begin{cases} (e^{-0.15y} + 1), & y \leq L/2 \\ (e^{-0.15(L-y)} + 1), & y > L/2 \end{cases} \quad (8)$$

where n_y is the coefficient of variation of porosity along the y -axis direction; L is the length of the retrieval face, m; and y is the value of the y -axis coordinate of a point in the gob, m.

The porosity variation coefficient along the z -axis direction is related to the z -axis coordinate value as shown in eq 9.

$$n_z = 1.05^z \quad (9)$$

where n_z is the coefficient of variation of porosity along the z -axis direction and z is the coordinate value of the z -axis at a point in the gob, m.

Equations 7–9 can be multiplied together to obtain the porosity distribution relationship within the gob. The expression of the distribution function is^{31,32}

$$n(x, y, z) = \begin{cases} (0.2e^{-0.0223x} + 0.1)(e^{-0.15y} + 1) \bullet 1.05^z, & y \leq L/2 \\ (0.2e^{-0.0223x} + 0.1)(e^{-0.15(L-y)} + 1) \bullet 1.05^z, & y > L/2 \end{cases} \quad (10)$$

where $n(x,y,z)$ is the porosity, a dimensionless coefficient, and L is the length of the working face, m.

Equation 10 is brought into the Blake–Kozeny equation to obtain the formula for the permeability of the gob.^{33,34}

$$k(x, y, z) = \frac{D_p^2}{150} \frac{n(x, y, z)^3}{[1 - n(x, y, z)]^2} \quad (11)$$

where $k(x,y,z)$ is the permeability, m^2 , and D_p is the average particle size of the collapsed rock in the gob, taken as 250 mm.

The porosity distribution of the gob is optimized according to eq 10 of the porosity distribution of the gob, combined with the actual measurement data, and constructed in MATLAB, as shown in Figure 4.

According to the porosity distribution eq 10 of the gob, combined with the following formula, the coefficient of viscous

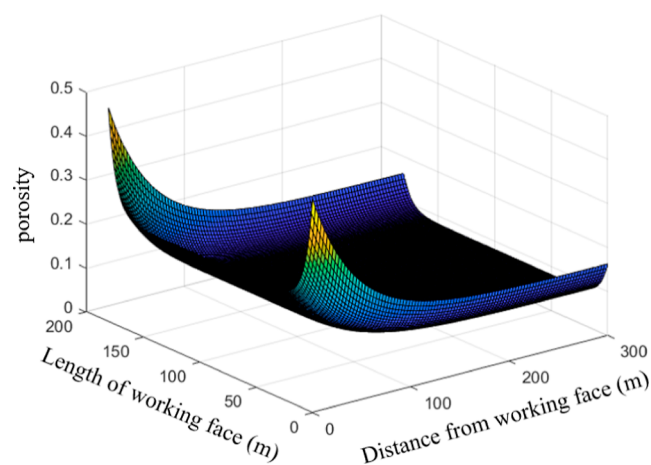


Figure 4. Distribution of porosity in the gob.

resistance and the inertial resistance coefficient of the gob can be calculated.

$$C_1 = \frac{1}{k(x, y, z)} = \frac{150 [1 - n(x, y, z)]^2}{D_p^2 n(x, y, z)^3} \quad (12)$$

$$C_2 = \frac{3.5[1 - n(x, y, z)]^2}{D_p n(x, y, z)^3} \quad (13)$$

where C_1 is the coefficient of viscous resistance, equal to the reciprocal of permeability, a dimensionless coefficient; C_2 is the coefficient of inertial resistance, a dimensionless coefficient; $k(x, y, z)$ is the permeability, m^2 ; D_p is the average particle size of the collapsed rock in the gob, mm; and $n(x, y, z)$ is the porosity of the gob, a dimensionless coefficient.

3.2. Gas Dispersion Pattern in the Gob. The rate of relic coal gas gushing from different depth locations in the gob is different, and its formula³⁵ is

$$q(y) = ae^{-b(y/v)} \quad (14)$$

where a is the initial strength of coal gas gushing out from the gob, m^3/min ; b is the attenuation coefficient of coal gas gushing out from the gob, min^{-1} ; y is the distance of coal gushing out from the working face, m; and v is the average mining velocity of working face, m/d.

3.3. Conservation Control Equation Parameters. The source term part of the control equation in FLUENT hydrodynamic numerical simulation software is modified by a user-defined function (UDF), a custom function, specifically using the DEFINE_PROFILE macro and DEFINE_SOURCE macro, and the settings of the porosity distribution, viscous resistance coefficient, and inertial resistance coefficient in the gob are adopted from the DEFINE_PROFILE macro, and the settings of the gas gushing source and oxygen dissipation in the gob are adopted from the DEFINE_SOURCE macro.

The air flow process in the working face and the intake and return airflow roadways is solved by the N–S equation system using the RNG k – ϵ model, and the low Reynolds number flow is carried out in the gob, so the differential viscosity model is used. The SIMPLE algorithm is used for pressure coupling, and the pressure discrete term is in PRESTO! Order upwind to improve the convergence accuracy.

3.4. Physical Parameter Setting and Boundary Condition Setting. In order to ensure the safe and efficient mining of the 215101 working face, according to eq 14, the absolute gas gushing out from the caving band and slit band is compiled by UDF and imported into FLUENT; the natural gas gushing out is measured by field sampling, and the natural gas gushing out is measured at different times, and regression analysis is performed according to eq 14. As shown in Figure 5, the initial intensity of gas gushing out from the gob is found to be $0.015 \text{ m}^3/\text{min}$, and the attenuation coefficient of gas gushing from the gob is 0.002 min^{-1} . The void ratio, viscous resistance, and inertial resistance are compiled according to eqs 10, 12, and 13 for UDF and imported into FLUENT. The wind speed is selected as 1, 1.5, 2, and 2.5 m/s according to the similar working face, and the mining velocity is selected as 1, 2, 3, and 4 m/d, simulated by FLUENT numerical simulation software, and the parameter design is shown in Table 1.

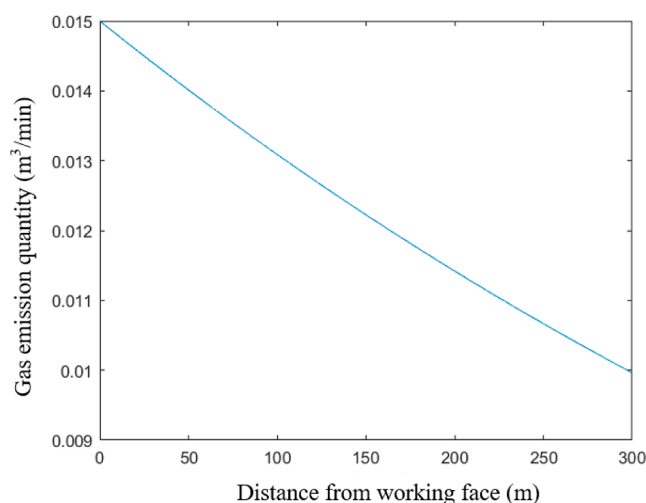


Figure 5. Gas emission quantity.

Table 1. Physical Parameter and Boundary Condition Setting

parameter name	parameter setting
initial strength of gas gushing from the gob/ (m^3/min)	0.015
attenuation coefficient of gas gushing out from the gob/ min^{-1}	0.002
average thickness of coal left in the gob/m	0.3
wind speed of the intake airflow roadway/ (m/s)	1/1.5/2/2.5
mining velocity of the working face/ (m/d)	1/2/3/4
absolute gas gush from the slit band/ (m^3/min)	UDF
absolute gas gush from the caving band/ (m^3/min)	UDF
porosity, viscous resistance, inertial resistance	UDF

4. NUMERICAL SIMULATION RESULTS AND ANALYSIS

4.1. Influence of the Wind Speed of the Intake Airflow Roadway on the Gas Distribution in the Gob. In order to get the optimal wind speed of the 215101 working face of the Yue Nan coal mine, the gas distribution in the gob and upper corner of the working face at different wind speeds of the intake airflow roadway was studied by using the unique variable method, in which only the wind speed of the intake airflow roadway was changed without changing other conditions. The above conditions were used for numerical simulations, and the simulation results were processed by CFD-Post software, and the gas concentration was analyzed by intercepting the plane of the gob at a height of 2 m, as shown in Figure 6.

Comparing with Figure 6, it can be seen that the gas distribution law in the gob is generally consistent, but as the wind speed of the intake airflow roadway gradually increases from 1 to 2.5 m/s, the wind flow from the working face into the gob gradually increases. Along the strike direction, the gas concentration on the inlet side gradually decreases, and the gas concentration on the return side changes less; along the tendency direction, the gas concentration in the gob 0–80 m changes less, the gas on the inlet side in the gob 80–200 m decreases as the wind speed increases, and the gas concentration on the return side changes less. With the increase of wind speed and decrease, the gas concentration on the return side changes less; after 200 m in the gob, the wind flow is slow, and the gas concentration basically remains stable.

When the wind speed of the intake airflow roadway was 1, 1.5, 2, and 2.5 m/s, the gas concentration in the upper corner of the

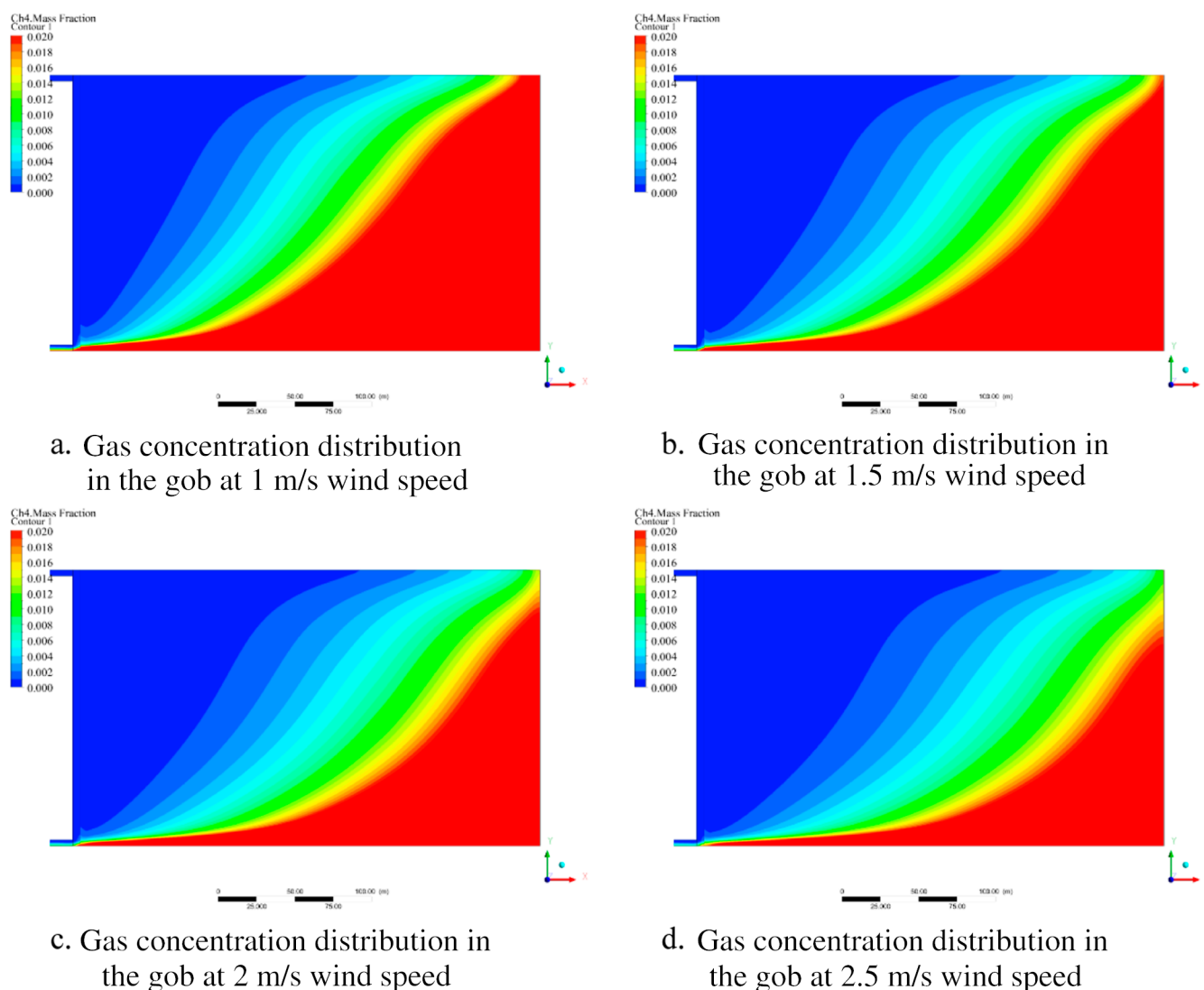


Figure 6. Distribution of the gas concentration in the gob at different wind speeds. (a) Gas concentration distribution in the gob at 1 m/s wind speed. (b) Gas concentration distribution in the gob at 1.5 m/s wind speed. (c) Gas concentration distribution in the gob at 2 m/s wind speed. (d) Gas concentration distribution in the gob at 2.5 m/s wind speed.

working face was 0.78, 0.52, 0.39, and 0.32%, respectively. The gas concentration in the upper corner decreased by 0.26% when the wind speed of the intake airflow roadway increased from 1 to 1.5 m/s; the gas concentration in the upper corner decreased by 0.13% when the wind speed of the intake airflow roadway increased from 1.5 to 2 m/s; the gas concentration in the upper corner decreased by 0.07% when the wind speed of the intake airflow roadway increased from 2 to 2.5 m/s. In summary, it can be seen that the greater the wind speed of the intake airflow roadway, the lower the upper corner gas concentration on the working face, which is conducive to the upper corner gas management on the working face, but in practice, we should consider the impact of the wind speed on the staff in the working face and various factors of economic benefits, so the wind speed of the intake airflow roadway set to about 2 m/s is more appropriate.

4.2. Influence of the Mining Velocity on the Gas Distribution in the Gob. In order to get the most suitable mining velocity of the 215101 working face of the Yue Nan coal mine, the gas distribution in the gob and upper corner of the working face at different mining velocities of the working face

was studied. Under the condition that other factors remain unchanged, only the mining velocity is changed so that the gas distribution in the gob can be studied. According to the study of the gas concentration distribution in the gob at different mining velocities, the wind speed of the intake airflow roadway is set to 2 m/s, and the mining velocity of the working face is set to 1, 2, 3, and 4 m/d, respectively in the UDF. A numerical simulation is carried out using the above conditions, and the simulation results are processed by CFD-Post software, and the gas concentration is analyzed by intercepting the plane of the gob at a height of 2 m, as shown in Figure 7.

Comparing with Figure 7, it can be seen that the gas distribution in the gob is basically the same but with the increase of mining velocity, the gas gushing from the gob increases, resulting in the increase of gas concentration in the gob. In the case of a fixed wind speed of the intake airflow roadway, the wind flow affects the same area; the wind flow from 0 to 70 m in the gob has a greater impact on the gas concentration in the gob, and the increase in mining velocity has a lesser impact on the gas concentration in the gob; the wind flow from 70 to 150 m in the gob has a lesser impact on it, and the increase in mining velocity

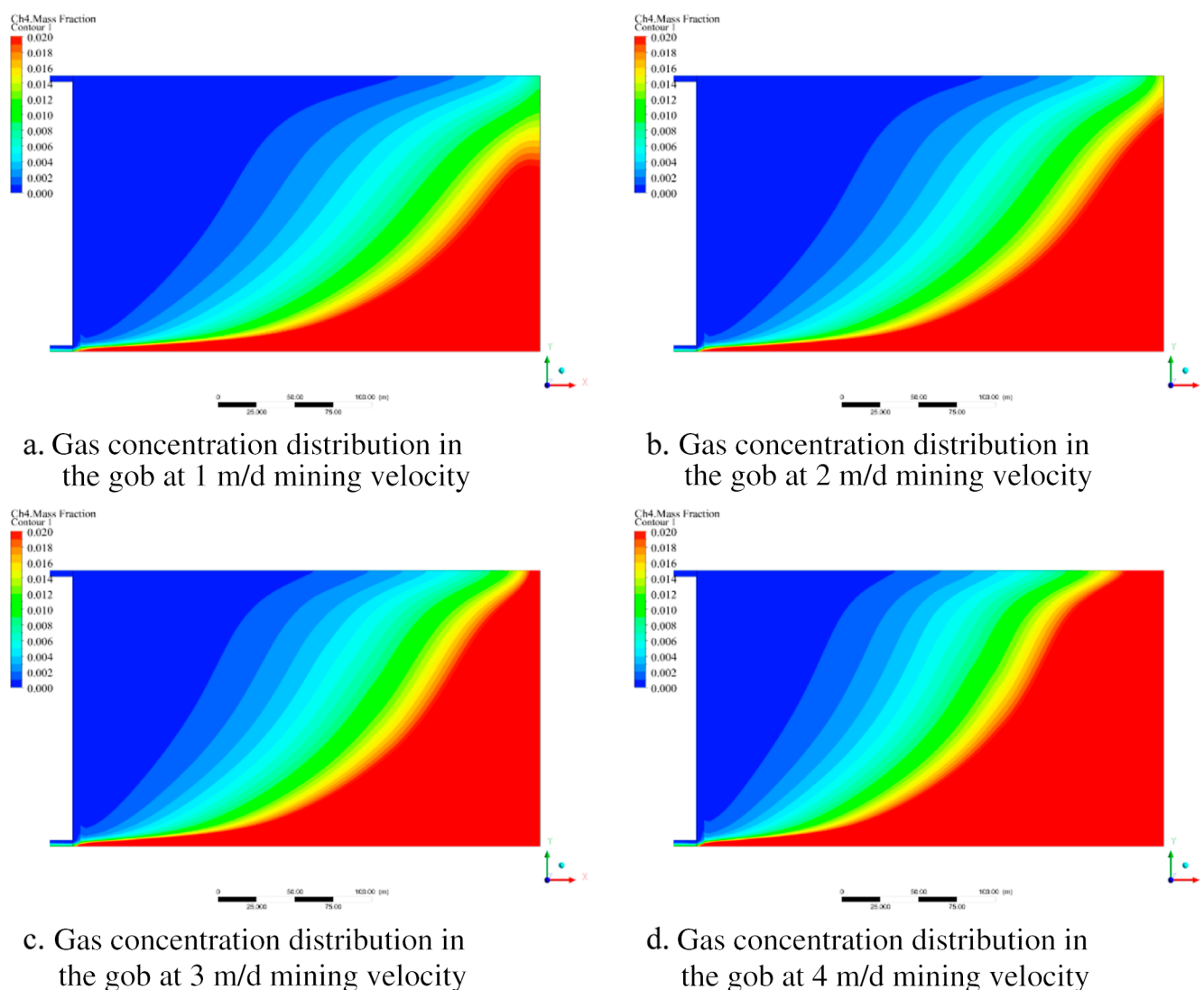


Figure 7. Distribution of the gas concentration in the gob under different mining velocities. (a) Gas concentration distribution in the gob at 1 m/d mining velocity. (b) Gas concentration distribution in the gob at 2 m/d mining velocity. (c) Gas concentration distribution in the gob at 3 m/d mining velocity. (d) Gas concentration distribution in the gob at 4 m/d mining velocity.

leads to an increase in gas concentration outflow, resulting in an increase in gas concentration on the return side; after 150 m in the gob, the wind flow has almost no influence on it, the gas gushing out in the extraction area increases, and the wind flow cannot carry out the gas, resulting in the internal gas gathering and the gas concentration increasing.

When the mining velocity of the working face is 1, 2, 3, and 4 m/d, the gas concentration in the upper corner is 0.27, 0.39, 0.58, and 0.83%, respectively. When the mining velocity increases from 1 to 2 m/d, the upper corner gas concentration on the working face increases by 0.12%; when the mining velocity increases from 2 to 3 m/d, the upper corner gas concentration on the working face increases by 0.19%; when the mining velocity increases from 3 to 4 m/d, the upper corner gas concentration on the working face increases by 0.25%. In summary, it can be seen that as the working face mining velocity increases, the upper corner gas concentration on the working face increases, which is not conducive to the upper corner gas management, but in actual production, considering mechanical equipment, staffing, mine safety, and other factors, the working face mining velocity should be about 3 m/d.

4.3. Analysis of the Flow Field in the Gob. According to the above parameters' selection, the wind speed of the intake airflow roadway is set to 2 m/s, that is, the air intake volume is 1920 m³/min, and the working face mining velocity is 3 m/d, and the flow field of the gob is simulated, and CFD-Post and Tecplot software are used to process the simulation results, as shown in Figures 8–10.

Figure 8 shows the pressure cloud map of the gob. As seen from the figure, the air pressure near the intake airflow roadway in the gob is greater than the air pressure near the return airflow roadway; the highest point of air pressure at the working face is located at the lower corner, and the lowest point is located at the upper corner, and the pressure gradient on both sides of the working face is the largest, and the pressure difference is the reason for the formation of the wind flow, so the air leakage area in the gob is mainly at the lower corner of the working face, and the return area is mainly at the upper corner of the working face.

Figure 9 shows the wind flow line diagram of the gob. As shown in the diagram, the wind leakage area is in the front half of the working face; the main leakage area is concentrated in the lower corner of the intake airflow roadway; most of the leakage

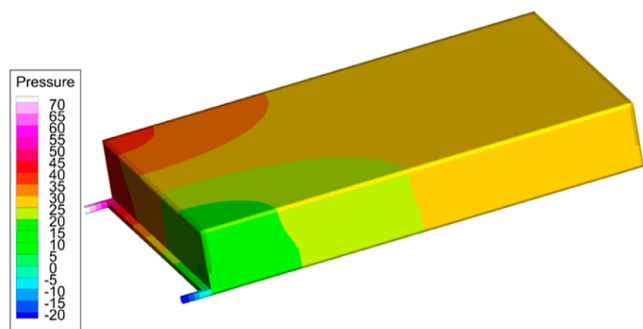


Figure 8. Pressure distribution of the working face and gob.

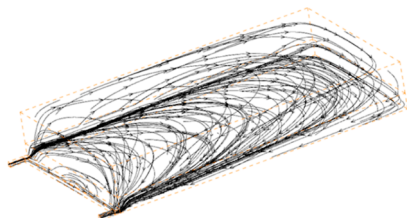


Figure 9. Flow line of the working face and gob.

wind flow flows into the caving band and flows to the depth of the gob; a small part of the leakage wind flow flows into the slit band through the caving band; the return wind area is in the upper corner of the return airflow roadway and the back half of the working face, mainly in the upper corner of the return airflow roadway. From the air leakage of the working face shown in Figure 10, we can see that the air leakage of the working face is at 0–90 m of the inlet side of the working face; the total air leakage is 1036.57 m³/min, accounting for 53.99% of the total air intake volume, in which the air leakage is more concentrated at 0–30 m of the working face; the air leakage is 806.86 m³/min, accounting for 77.84% of the total air leakage; the wind flow gathering area of the working face is mainly at 90–180 m of the working face, mainly concentrated at 150–180 m of the working face; the return air volume is 790.88 m³/min, accounting for 76.30% of the total return air volume.

The occurrence of a disaster in the gob is due to the formation of a certain disturbance effect between the working face and the gob during the exchange of the wind flow. When the disturbance is small, no disaster will occur in the gob, and when the

disturbance reaches a certain degree, a disaster will occur in the gob. When the wind speed is less than 0.00167 m/s, it can be regarded as no wind leakage.³⁶ The wind flow disturbance area is divided according to the wind speed size, and the wind speed less than 0.00167 m/s area is defined as the wind flow undisturbed area; the wind speed of 0.00167–0.00260 m/s area is defined as the wind flow slightly disturbed area; the wind speed of 0.00260–0.00400 m/s area is defined as the wind flow moderately disturbed area; the wind speed greater than 0.00400 m/s area is the wind flow strongly disturbed area. From the wind velocity distribution map in Figure 10, it can be seen that along the strike direction, the lesser the distance to the working face, the greater the wind velocity; the 0–50 m range of the gob belongs to the wind flow strongly disturbed area; the wind velocity is larger, and the wind flow carries more gas from the gob, which is the main area of the upper corner gas source on the working face. The 50–62 m range of the gob belongs to the wind flow moderately disturbed area; the wind velocity is lower, and the wind flow carries less gas from the gob, which is the secondary area of the upper corner gas source on the working face. The 62–75 m range of the gob belongs to the wind flow slightly disturbed area; the wind velocity is weak, and the wind flow carries a small amount of gas, which has less impact on the upper corner gas concentration on the working face. After 75 m of the gob is the wind flow undisturbed area, this area is not affected by the wind flow, and the upper corner gas concentration is almost not affected by this area.

4.4. Gas Distribution Pattern and Analysis in the Gob.

We set the wind speed of the intake airflow roadway to 2 m/s and the working face mining velocity to 3 m/d; other parameters remain unchanged. The gas distribution in the gob is simulated, and the gas distribution in the gob is shown in Figures 11 and 12. Also, extract gas concentration data inside the gob are shown in Figures 13–15.

From the distribution of the gas concentration in the gob, along the strike direction, as shown in Figure 13, it can be seen that the gas concentration on the inlet side gradually increases from 0 to 1.58% with the increase of the depth of the gob, and the gas concentration on the return side gradually increases from 0.58 to 8.90% with the increase of the depth of the gob; both tend to stabilize in the deep part of the gob, mainly because the wind speed gradually decreases when the working face reaches the deep part of the gob, and the influence on the gas gradually weakens. Along the tendency direction, as shown in Figure 14,

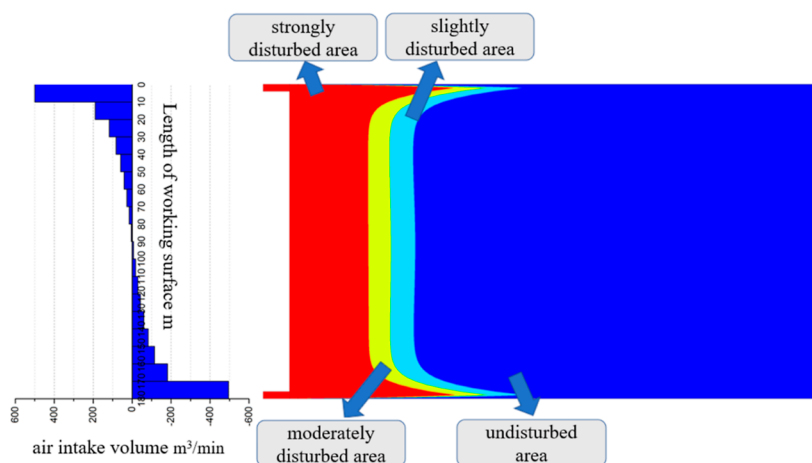


Figure 10. Distribution of the air leakage and wind speed at the working face.

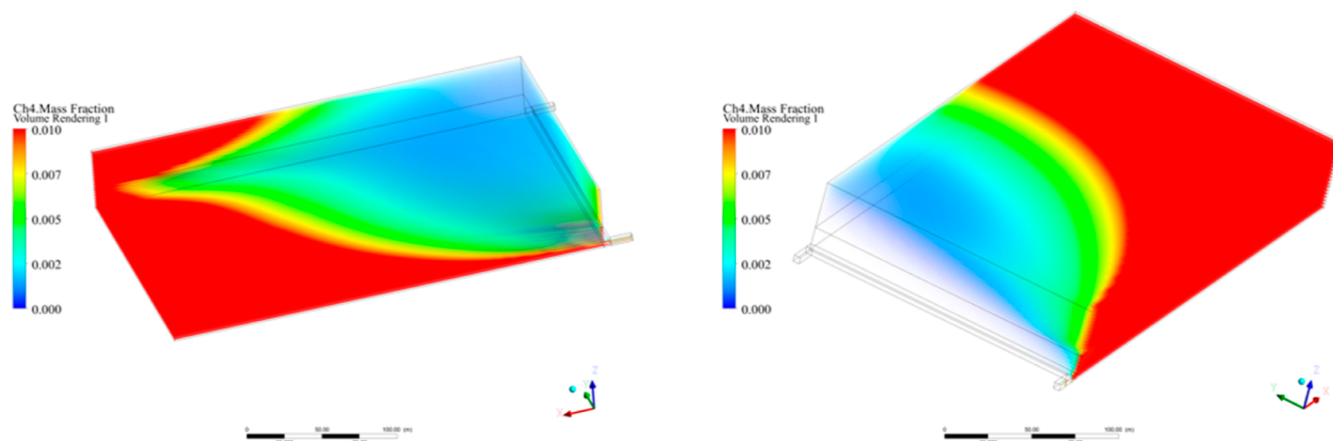


Figure 11. Overall map of the gas concentration distribution in the gob.

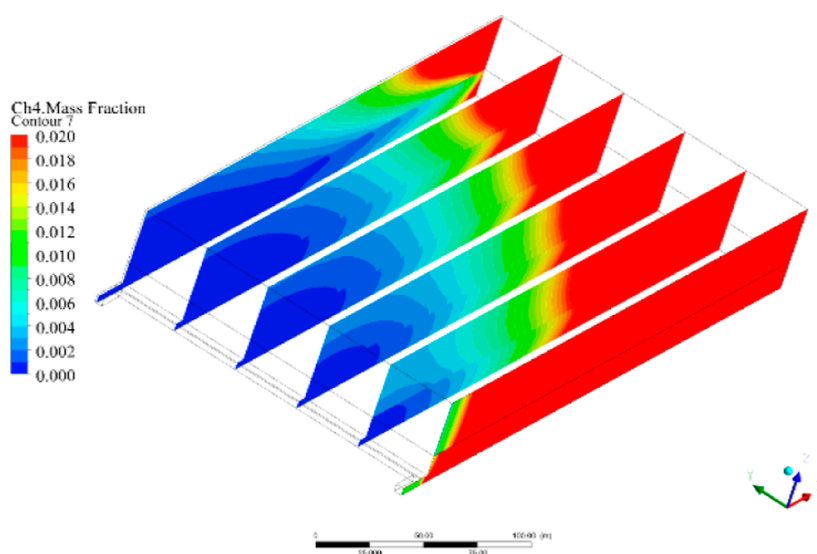


Figure 12. Gas distribution along the strike direction.

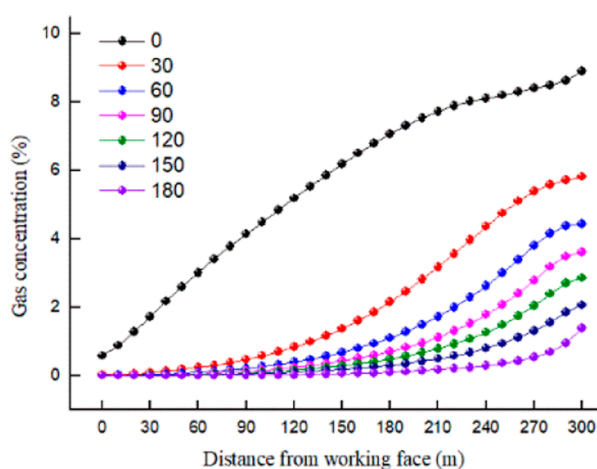


Figure 13. Gas concentration in the gob along the strike direction.

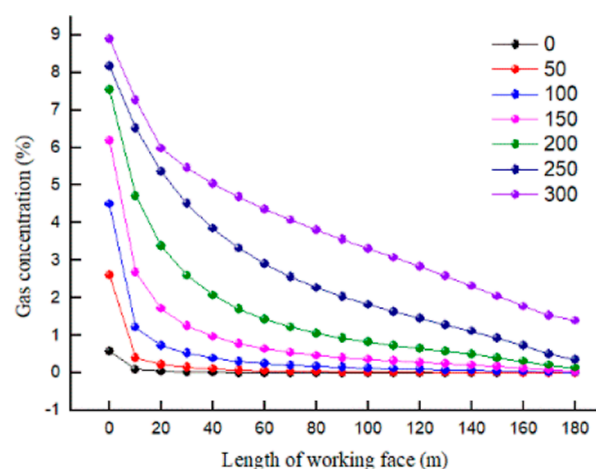


Figure 14. Gas concentration in the gob along the tendency direction.

the gas concentration in the shallow part of the gob gradually increases from 0 to 0.58% from the inlet side to the return side, and the gas concentration in the deep part of the gob gradually increases from 1.58 to 8.90% from the inlet side to the return side, mainly because the pressure in the return airflow roadway is lower than the pressure in the intake airflow roadway, thus

forming a pressure gradient, and the fresh wind flows into the gob from the working face, and the wind flow carrying the gas flows into the working face from the gob. The fresh air flows from the working face into the air gob, and air carrying the gas from the air gob flows into the working face. Also, the inlet side of the working face is the leakage area, and the return side is the

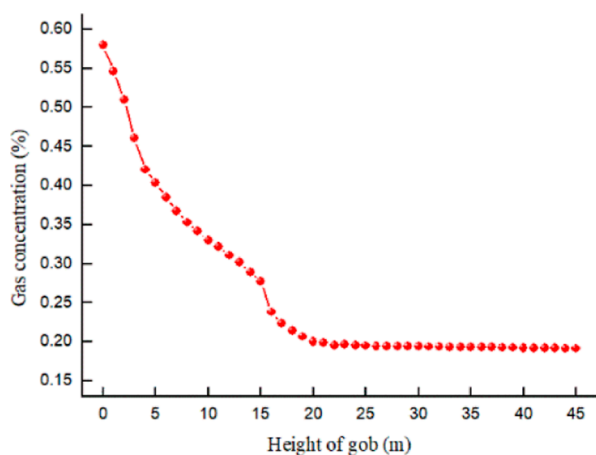


Figure 15. Gas concentration in the upper corner along the vertical direction.

wind flow gathering area; a large amount of leakage wind flow carries the gas from the gob to gather in the corner of the working face, which will easily cause the upper corner to exceed the gas limit.

Along the vertical direction, the gas concentration in the gob gradually increases from the bottom of the caving band to the top of the slit band, and the gas concentration in the return side of the gob gradually decreases from the bottom of the caving band to the top of the slit band. Although the gas gushing out from the caving band is more than that from the slit band, because the wind speed is higher and the void rate of the slit band is lower than that of the caving band, the wind speed of the caving band is higher and the wind flow carries more gas, while the wind flow of the slit band is lesser and carries less gas, resulting in the gas concentration of the caving band being lower than that of the slit band; however, the upper corner is the convergence area of the wind flow, a large amount of gas converges in the upper corner with the leakage wind flow, resulting in the gas concentration of the caving band at the upper corner being more than that of the slit band, as shown in Figure 15.

5. DISCUSSION

In this paper, the optimal mining conditions are selected by using numerical simulations before mining, which effectively reduces mine accidents caused by unsuitable mining conditions, reduces the probability of mine accidents, and provides a theoretical basis for the safe mining at similar mines.

Comparing with some other literature studies^{6,18,19} on the wind flow and gas transportation, the form of ventilation and the amount of ventilation changed, but they all present large air leakage at large porosity, large air flow inside the gob near the working face, and small air flow away from the working face; the overall wind flow distribution is similar. Comparing with the gas distribution law in the gob, they all show that the gas concentration on the leakage side is lower than the gas concentration on the return side, and the gas concentration in the shallow part of the gob is smaller than the gas concentration in the deep part of the gob, and the gas distribution law in the gob is similar, which provides strong evidence for the accuracy of the research study on the gas outflow characteristics in the upper corner of this paper.

By analyzing the gas gushing characteristics of the upper corner on the working face, the optimal air intake volume and

working face mining velocity are determined. However, due to the complex structure of the gob, the distribution of porosity needs to be decided according to the lithology, crushing and swelling coefficient, collapse degree, and so forth. It is impossible to set the parameters of the porosity of the gob in detail, and we can only set the idealized porosity of the gob, and the ideal situation has errors with the porosity of the actual situation, which will affect the exchange amount of the wind flow between the working face and the gob; when the setting of the porosity of the gob is small relative to the actual porosity, the gas exchange between the working face and the gob is less, resulting in the gas gushing from the gob, and the upper corner is large, and vice versa, it is small. As the gas gushing out from different locations inside the gob is different, this paper shows that the gas gushing out mainly contains three parts: gas gushing out from the neighboring layer, gas gushing out from the neighboring working face, and gas gushing out from the coal remains, among which the gas gushing out from the coal remains is idealized according to the initial strength of gas gushing out from the coal remains in the gob, the attenuation coefficient of gas gushing out from the coal remains in the gob, the distance of the coal remains from the working face, and the average advance speed of the working face. Considering that the actual gas gush has a part of the error, when the gas gush is large, the gob and the upper corner gas gush will be large relative to the actual gas gush, and vice versa, it is small. In order to ensure safe mining, the mine environment is assumed to be more dangerous than the site environment, which will result in a larger inlet air volume and lower advance speed.

Through the analysis of the gas in the gob, it can be said that with an increase of wind speed, the gas concentration in the upper corner decreases, but the amount of air leakage increases, which leads to the increase of oxygen in the gob and the increase of disaster rate in the gob; with the increase of working face mining velocity, the gas gushing out from the gob increases, and the gas concentration in the upper corner increases accordingly, which leads to the increase of disaster rate in the upper corner. From the viewpoint of the wind flow exchange between the working face and the gob, the air leakage from the working face is large, and the main air leakage area is concentrated in the inlet side, and the wind flow compensation area is mainly concentrated in the return side; this is the main factor influencing the gas concentration in the upper corner, so it is necessary to carry out wind leakage prevention and plugging measures on the inlet and return side. From the site data, under the best mining conditions, the gas concentration of the upper corner and return air lane on the 215101 working face was measured, and the measurement results are shown in Figure 16. The maximum gas concentration of the upper corner is 0.18%, and the maximum gas concentration of the return airflow roadway is 0.14%, and the gas concentration did not exceed the limit.

From the above discussion, the gas concentration in the upper corner of the working face of the Yue Nan 215101 back mining is low, so there is no need for gas extraction, but the wind leakage from the working face is more serious, which is likely to lead to mine disasters. In order to prevent the occurrence of mine disasters, hanging a wind tent is a simple and effective preventive measure to prevent wind leakage from the working face. Hanging a wind tent at 0–30 and 150–180 m of the working face can effectively prevent the wind flow from the working face from converging into the gob, reduce the occurrence of mine

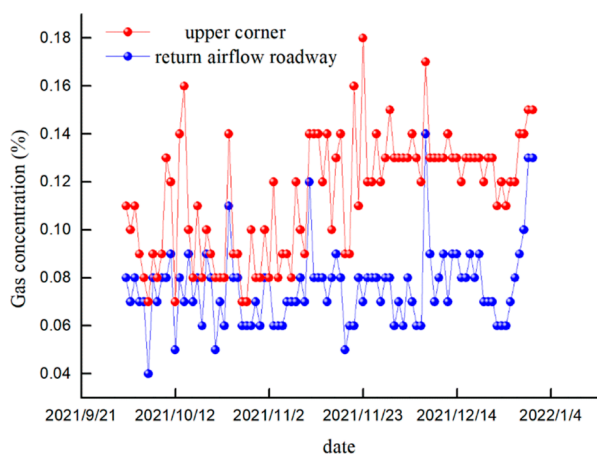


Figure 16. Upper corner and return airflow roadway gas concentrations.

disasters, and guarantee the safe and efficient mining of the working face.

6. CONCLUSIONS

In this paper, by using FLUENT software to simulate the 215101 working face of the Yue Nan coal mine under different wind speed and mining velocity conditions, the best wind speed of the intake airflow roadway and working face mining velocity were selected, and the upper corner of the working face and the gas gushing characteristics of the gob under these conditions were analyzed, and the main research results are as follows.

- (1) By comparing the simulation results, according to the gas concentration in the upper corner, the best wind speed of the intake airflow roadway was determined to be 2 m/s, and the working face mining velocity was 3 m/d.
- (2) Through the simulation analysis of the wind flow transport law in the gob, the influence of the wind flow in different areas of the gob on the gas gushing from the upper corner was analyzed, and the wind flow disturbance area is divided according to the degree of influence. Also, the source of wind flow in the gob is analyzed, the main source of the wind flow in the gob is concentrated in 0–30 m on the inlet side of the working face, and the main wind flow gathering area is concentrated in 150–180 m on the return side of the working face, which is the main factor of the gas source in the upper corner.
- (3) Through simulating and analyzing the gas transportation law in the gob, it is found that along the direction, the gas concentration in the gob gradually increases from the working face to the depth of the gob; along the tendency direction, the gas concentration gradually increases from the inlet alley to the return alley of the working face, and the gas reaches the maximum at the upper corner; along the vertical direction, the gas concentration in the gob gradually increases from the bottom of the caving band to the top of the slit band, and the gas concentration at the upper corner gradually decreases from the bottom of the caving band to the top of the slit band. The gas concentration at the upper corner gradually decreases from the bottom of the caving band to the upper part of the slit band.

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Notes

The authors declare no competing financial interest.

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