Arch. Min. Sci. **67** (2022), 4, 715-728

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI: https://doi.org/10.24425/ams.2022.143683

YONGZHEN MA[1], JIANWEI CHENG[1*], RUI ZHANG[1],
ZUI WANG[1], DEZHI RAN[1], SHUPING SHENG[1],
JUFENG ZHANG[2], JUNHONG SI[3], ZHAOYANG YU[4]

USING HIGH LEVEL ROADWAY TO CONTROL GAS EMISSION IN A LONGWALL MINING FACE – NUMERICAL SIMULATION STUDY

With the increase of coal mining depth, the gas content in coal seams could also become larger and larger, which could suddenly cause an inrush of gas into the longwall mining face. It is very dangerous for miners' safety in the underground. The U-shaped ventilation pattern of longwall mining face that underground coal mines currently use is not enough to deliver sufficient air quantities to dilute gases in mining faces, which could result in the gas concentration over the required celling limit by government laws. Thus, the mine must stop production. In this paper, the high level roadway (HLR) is designed and the U + HLR new ventilation pattern is proposed to control gas emission in a longwall mining face. Using computational fluid dynamics simulation (CFD) software, the flow field and gas transportation in the mine gob are studied. The optimized ventilation parameters are summarized. It is found that the best vertical distance of the HLR is 35 m over the coal seam and the horizontal distance is 25 m from the air return roadway. It is recommended that the negative suction pressure design of the high level roadway should be ranged from 9000 Pa to 10000 Pa. Based on the study outcomes, the gas emission could be well controlled in mining faces and avoid any gas disaster accidents.

Keywords: high level roadway; gob; numerical simulation; U+HLR ventilation method

1. Introduction

The coal industry has always been an accident-prone and high-risk industry, and the multiplicity and severity of coal mine gas accidents are great challenges for coal mine safety produc-

[1] CHINA UNIVERSITY OF MINING AND TECHNOLOGY, CHINA
[2] LONGDONG UNIVERSITY, CHINA
[3] NORTH CHINA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHINA
[4] GUIZHOU UNIVERSITY, CHINA

* Corresponding author: Cheng.Jianwei@cumt.edu.cn

tion in China [1]. In addition this, 95% of coal mines are mined by shaft mining [2], and all of them are gassy mines, with 26.8% of high gas mines and up to 17.6% of mines with coal and gas prominence in the key coal mines of state-owned enterprises [3]. Therefore, solving the gas problem in the gob plays a vital role in greatly improving the gas problem in coal mines, as well as for the safe production of mines and improving the economic efficiency of mines.

The gas transport pattern in the vertical three zones and horizontal three zones is the theoretical basis for gas management in the gob and the upper corner [4]. Linear theory suggests that the movement of gas in a coal seam, such as seepage diffusion, is basically by the linear law of permeability, often referred to as Darcy's law [5]. Fick's law [6] states that the seepage motion of gas within the coal chip is linearly diffusive. Zheng et al. [7] argue that the diffusion theory of gas in coal chips can explain the gas gushing out under different mining conditions. In addition, Mark et al. [8] suggest that the application of Darcy's law to describe the emergent gas in coal seams is not compatible with experimental results. Sun [9] applies a power function extension form to pioneer a nonlinear flow model for gas flow in coal seams.

At present, there are various ways of gas extraction in China's mining areas. There is buried pipe extraction in the corner of the recovery workings, although these methods can achieve a better extraction effect and play a certain control role on the gas concentration in the upper corner, the gas flow state in the gob is difficult to control and does not achieve the expected extraction effect.

Under the U type ventilation method of mining face, with the increase of air volume, it will reduce the concentration of gas in the upper corner and mining face [10], and the increase of air volume will cause the increase of air leakage [11], and the gas brought out from inside the mining area will also increase, so the U type ventilation method does not solve the problem of gas exceeding the limit of mining face [12,13]. Therefore, it is urgent to solve the problem of gas extraction in the gob [14].

This paper proposes U+HLR new ventilation pattern to manage the corner gas on the mining face for the high gas gushing volume mining face, to solve the serious problem of the high frequency of gas overload in the lane and the sharp increase of gas concentration in the gob, which is very prone to a gas explosion accident. Through theoretical analysis and numerical simulation, this paper studies the gas transport law and flow field in the gob, and examines the gas transport law in the gob under the high level roadway. By studying the influence of different high level roadway locations and extraction pressure on the flow field distribution and gas transport law in the gob, the suitable high level roadway locations and negative suction pressure are determined, and measures are proposed to solve the gas overrun problem and reduce the possibility of gas disaster accidents.

2. Coal mine mining face background

The recoverable length of the mining face studied in this paper is 957 m, and the gas content of the mining face is 12 m^3/t, which is a class I gas management area. The mining face adopts the ventilation system of "one in and one out", after the mining face forms a full air pressure ventilation system, the estimated air distribution volume is 2800 m^3/min. Fig. 1 shows the coal seam inventory characteristics of the mining face.

Top plate name	Thickness(m)	Symbol	Level	Lithological description
Upper roof	7.3		1	Fine sandstone, grayish white, sandy colluvium, interbedded with mudstone.
Immediate roof	2.5		2	Sandy mudstone, gray-black, muddy cement, laminated, fissures developed.
15# Coal	5.7 4.6—6.53		3	Black, semi-glossy, flimsy.
Direct bottom	1.57		4	Siltstone, gray, with rhodochrosite and pyrite nodules, rich in plant roots and fossils.
Old background	6.1		5	Sandy mudstone, black, with rhodochrosite and pyrite nodules, with plant carbonates at the base.

Fig. 1. Coal seam storage characteristics of the working surface

3. Model and parameter setting of the gob

3.1. Basic assumptions

The gob is regarded as porous media model for the study of gas transport law in the gob, the following basic assumptions should be made.

(1) The porous medium in the gob, which is composed of the gangue and coal relic voids, will be approximated as isotropic.
(2) No chemical reaction occurs between the gas components in the gob, and the physical characteristics of each gas do not change, ignoring the effect of temperature changes on the gas characteristics parameters.
(3) Considering the gas in the gob as an incompressible ideal gas, the flow of the gas conforms to Darcy's law.
(4) Ignoring the diffusion effect of the gas and the heat exchange with the surrounding of the gob, the walls on both sides of the gob are isothermal.

3.2. Physical modeling of the gob and delineation of the computational grid

The physical model of the gob is established by Designmolder with the prototype of the mining area at the mining face, and the total air distribution volume of the mining face is 2800 m^3/min. The high-level high level roadway is arranged 20m above the mining face coal seam and 20 m away from the projection distance of the air return roadway, as shown in Fig. 2.

According to the actual situation on-site and the needs of numerical simulation, the geometric model of the mining face extraction zone was simplified to a certain extent, without considering the overburden unloading angle of the mining face, and the model of the extraction zone was built as a rectangular body for analysis and research. Table 1 shows the specific parameters of the air intake roadway and air return roadway.

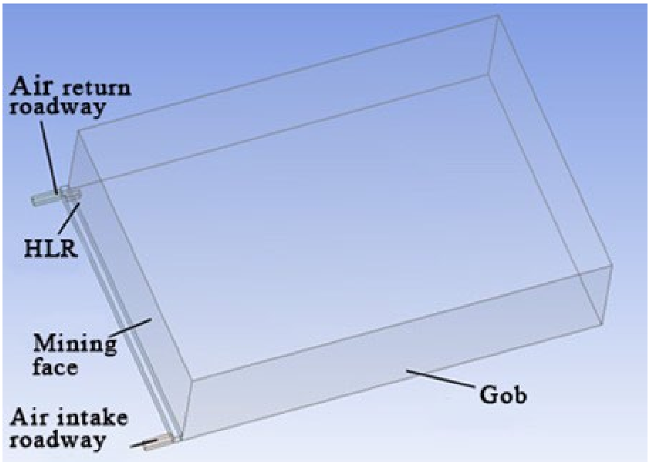

Fig. 2. 3D model of U+ high level roadway type mining area

TABLE 1

Parameters of the physical model of the mining face

Position	Geometry size x×y×z (m×m×m)
Mining face	200×6×5
Gob	300×200×60
HLR	10×3×4
Air intake roadway	20×5×3.2
Air return roadway	20×5×3.2

According to the basic principles of grid division, the three-dimensional model established by using MESH in the Cartesian coordinate system is gridded, and the grid spacing of 5 m is used for grid division of the gob, and the grid spacing of 1m is used for grid division of the roadway and mining face, and the part of the inlet and air return roadway is divided into 400 grids, the mining face area is divided into 6600 grids, and the gob is divided into 23232 grids. The geometric model grid division is shown in Fig. 3.

3.3. Boundary conditions setting

The inlet boundary condition is set as velocity inlet, the average airflow velocity is taken as 2.8 m/s, the gas concentration at the inlet is 0 and the oxygen concentration is 21%; the outlet boundary condition is set as free outflow boundary condition; the solid wall around the mining

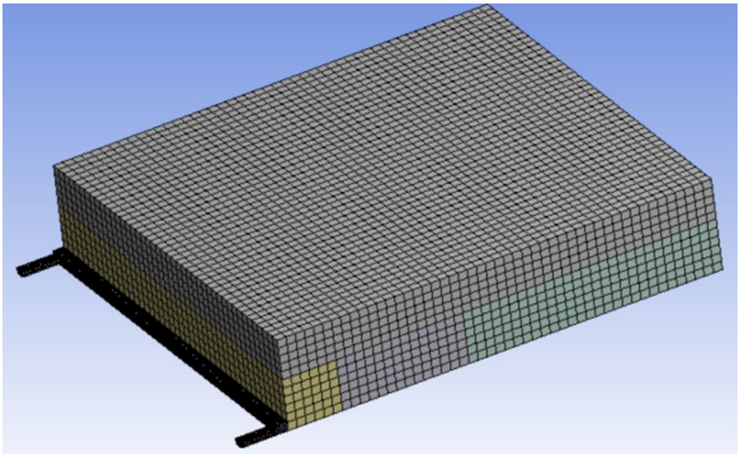

Fig. 3. Grid division of the physical model of the mining area of the mining face

face and the mining area is set as a no-slip boundary condition, i.e. $u = v = w = 0$; The intersection of mining face and mining area as well as caving zone and fracture zone is defined as internal face; the mining face is defined as fluid area; mining area is defined as fluid area and set as porous media area, wall temperature is the same as surrounding rock temperature, both are 300K. The gas in the gob mainly comes from the gas gushing out from the coal left in the gob and the gas gushing out from the surrounding rock, setting the total absolute gas gushing out from the coal wall and falling coal in the mining face to 29.08 m^3/min and the total gas gushing out from the mining area to 38.83 m^3/min.

3.4. Porous media parameters

3.4.1. Determination of viscous drag coefficient and porosity

Since the fracture pore space varies in different areas within the mining area, the surface resistance of fluid transport in different pore spaces also varies, so the viscous resistance coefficients of different areas are set to better simulate the fluid transport state at the intersection. Rock permeability and coefficient of viscous resistance are inversely related, according to the relationship between rock porosity and rock fragmentation and expansion coefficient, the coefficient of viscous resistance of rocks in different areas can be calculated by the following formula:

$$m = 1 - \frac{1}{C_P} \tag{1}$$

$$L = \frac{1}{N} = \frac{150(1-m)^2}{{D_m}^2 m^3} \tag{2}$$

m: Rock porosity; C_P: Rock fragmentation and expansion factor; L: Viscous resistance coefficient; D_m: Particle diameter; N: Penetration.

The void ratio of the fallen rock in the gob satisfies the following equation:

$$\varphi_G(x,y)=1+\frac{\left[1+e^{-0.15\left(\frac{l_y}{2}-|y|\right)}\right]\cdot\left\{1-\frac{h_d}{h_d+H-\left[H-h_d\left(K_{P_b}-1\right)\right]\left(1-e^{\frac{x}{2l}}\right)}\right\}-1}{1+\sigma_0^{-1}\beta_1\gamma\left(\frac{l_y}{2}-y\right)\sin\alpha} \tag{3}$$

When the fallen rock is shale $\beta_1=-0.0488$. When the rockfall is mudstone $\beta_1=-0.028$. When the fallen rock is sandstone $\beta_1=-0.0254$.

Based on the Kozeny-Carman relationship between permeability and void fraction and the results of Hoek and Bray's study of the Kozeny-Carman relationship:

$$k=\frac{\varphi^3}{(1-\varphi)^2}\left(F_S{}^2S^2S_{gv}{}^2\right)=\frac{k_0}{0.241}\cdot\frac{\varphi^3}{(1-\varphi)^2} \tag{4}$$

In the formula: k is the penetration rate, μm^2; φ is the void ratio; F_s is the form factor; S is tortuous; S_{gv} is the surface area of the particles contained in the unit mass medium; k_0 is the benchmark penetration rate, take value 10^3 μm^2. From this, the permeability within each area of the extraction zone and the overlying rock can be calculated.

3.4.2. Gas quality phase

Mining face gas gushing out mainly from the coal wall, coal fall and gas gushing out of the empty area, and gas gushing out of the empty area occupies a large part of the proliferation of gas because the distribution of gas in the empty area is unknown, the amount of gas gushing out everywhere is also different, do idealization, that the gas gushing out of the empty area is uniformly distributed in the space of the gob. Set the mining face coal wall and fallen coal total absolute gas outflow is 29.08 m^3/min, the total gas outflow of the mine gob is 38.83 m^3/min, then we can find out the gas outflow source term of each area, the calculation formula is as follows.

$$Q_\varepsilon=\frac{Q_m\rho_m}{V} \tag{5}$$

Where: Q_ε is the gas mass source term in different regions, kg/m^3; Q_m is the absolute gas gush in different regions, m^3/s; ρ_m is the gas density, $\rho_m=0.717$ kg/m^3; V is the volume in each region, m^3.

From the above equation, we can obtain the gas quality source term for the mining face, fracture zone, and fallout zone. Although the gas gushing condition in the mining site is very complicated, the simulation needs to assume that the gas is in the average state in each zone of the extraction area, take the average fragmentation and expansion coefficient in the fall zone is 1.17 kg/(m^3·s), the mining face gas quality source is 5.79×10^{-5} kg/(m^3·s), and the extraction area gas quality source is 1.29×10^{-7} kg/(m^3·s).

4. Simulation study results

The extraction effect is greatly influenced by the location of the extraction opening of the high level roadway. 7 groups of comparison experiments are established, and the distance from the air return roadway is 15 m, 25 m, 35 m, and 45 m in the horizontal direction, and 15 m, 25 m, 35 m, and 45 m from the bottom of the extraction area in the vertical layer, respectively.

4.1. Determination of the optimal vertical distance for high level roadway

The horizontal distance of the high level roadway from the air return roadway is set to 25 m to simulate the effect of gas extraction with different arrangement heights at the same horizontal distance. The gas extraction effect of the high level roadway under different vertical distance conditions is mainly reflected by the gas concentration in the upper corner and the gas concentration in the extraction port of the high level roadway. The simulated extraction effects under different vertical levels are shown in Fig. 4 to Fig. 7.

Analyze and compare the effect of gas extraction under different pitches, record the gas concentration at the observation points under different pitches, and the results are shown in Table 2.

It can be obtained that with the increase of high level roadway layout height, the overall gas concentration in gob decreases, while the extraction concentration in high level roadway is

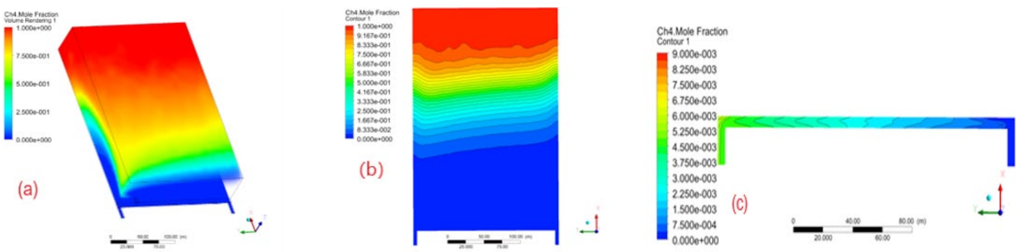

Fig. 4. Gas concentration distribution map at a horizontal distance of 25 m and a vertical height of 15 m in a high level roadway. (a) Stereoscopic view of gas concentration distribution at a vertical distance of 15 m, (b) Gas concentration slice plot at z = 1.7 m, (c) Mining face gas concentration slice plot

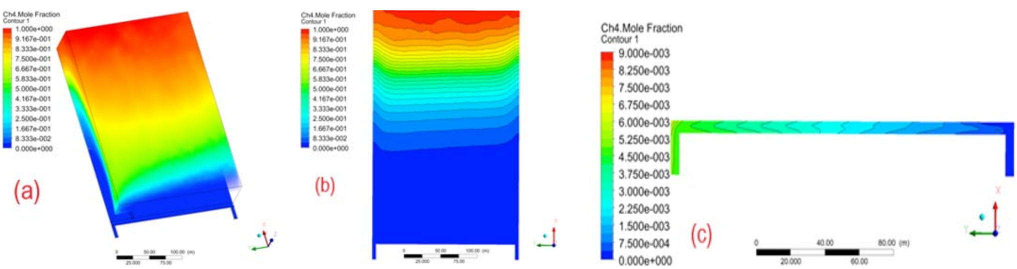

Fig. 5. Gas concentration distribution map at a horizontal distance of 25 m and a vertical height of 25 m in the high level roadway. (a) Stereoscopic map of gas concentration distribution at a vertical distance of 25 m, (b) Gas concentration slice plot at z = 1.7 m, (c) Mining face gas concentration slice plot

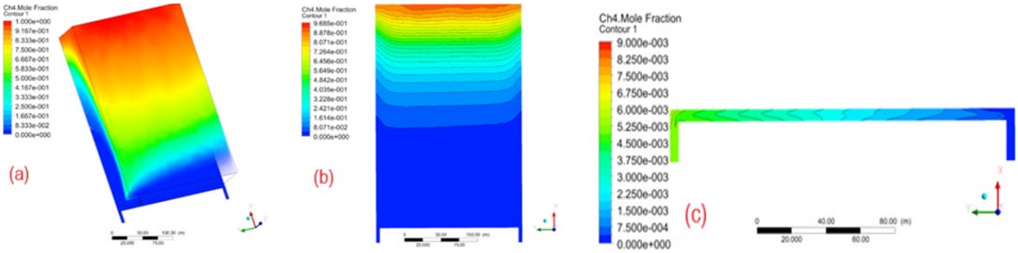

Fig. 6. Gas concentration distribution map at a horizontal distance of 25 m and a vertical height of 35 m in a high level roadway. (a) Stereoscopic plot of gas concentration distribution at a vertical distance of 35 m, (b) Gas concentration slice plot at z = 1.7 m, (c) Mining face gas concentration slice plot

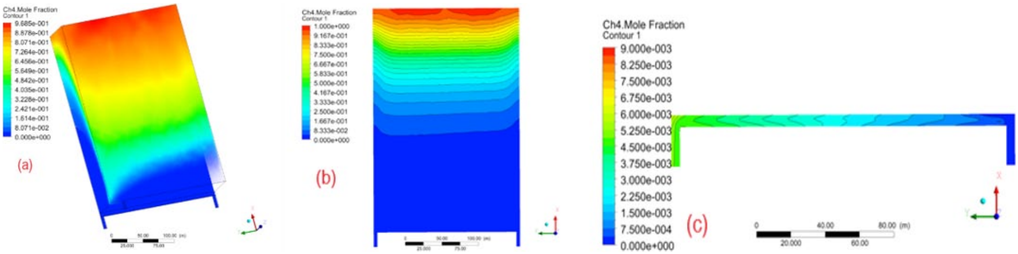

Fig. 7. Gas concentration distribution map at a horizontal distance of 25 m and a vertical height of 45 m in a high level roadway. (a) Stereoscopic map of gas concentration distribution at a vertical distance of 45 m, (b) Gas concentration slice plot at z = 1.7 m, (c) Mining face gas concentration slice plot

TABLE 2

Gas concentration in each roadway at different vertical distance of the mining face

Vertical distance / m	Gas concentration in return air corner	High level roadway gas concentration
15	0.596%	1.32%
25	0.58%	1.4%
35	0.588%	1.53%
45	0.599%	1.49%

increasing, and the extraction concentration decreases when it increases to the nearest position from the coal seam. The reason for this phenomenon is that between 25 m and 35 m of vertical distance, the high level roadway is arranged at a low level and close to the mining face, which can effectively extract gas from the mining face but has little effect on the gas extraction in the upper part of the fissure zone. Therefore, the height of the high level roadway needs to rise. When the high level roadway is arranged at 35 m, it is in the middle of the fissure zone, which can effectively extract the gas at the fissure zone and also take into account the upwelling gas coming out of the mining face. When the vertical distance is 45 m, the high level roadway is located in the middle and upper part of the fissure zone, which is far away from the mining face. Although some of the uplifted gas in the gob will be extracted, the effect on the uplifted gas extraction is minimal because it is far away from the bottom plate of the gob and the gas uplifting resistance is large.

Therefore, compared with the 35 m location, the concentration of extracted gas decreases, and at the same time, the gas inside the mining area will gradually accumulate because it cannot be effectively extracted in time, which increases the risk of spontaneous combustion and fire in the mining area. The higher the level of the high extraction tunnel, the higher the gas concentration in the upper corner, but it is within the range of 1%.

In summary, when the high level roadway is placed at a vertical distance of 35 m, the high level roadway extracts the maximum gas concentration, while the gas concentration in the upper corner is 0.588%. Therefore, the best arrangement of the high level roadway is 35 m.

4.2. Determine the best horizontal distance for high level roadway

According to the analysis and comparison of the gas extraction effect of the high level roadway with different dips, we determined that the best extraction effect of the high level roadway is at 35 m, so we also need to simulate the different extraction effects of the high level roadway with 35 m dip, 15 m, 25 m and 45 m from the air return roadway.

The extraction models of high level roadways with different horizontal distances were established, the extraction results were compiled and analyzed for comparison, and the three-dimensional maps of gas concentration distribution of extraction in high level roadways with different horizontal distances, the plane map of gas concentration distribution at z = 1.9 m, and the gas concentration distribution of mining face were intercepted. The extraction results are shown in Fig. 8 to Fig. 10:

The gas extraction effect was analyzed and compared at different horizontal distances, and the gas concentration at the observation points was recorded at a vertical distance of 35 m. The results are shown in Table 3.

It can be concluded that after determining the best vertical distance of 35 m, when the horizontal distance from the backwind lane is 15 m, under the influence of the negative suction pressure of the high level roadway, some of the wind flow of the backwind lane will surge into the high level roadway, which makes the high level roadway unable to extract high concentration of gas and will lead to the limitation of its extraction range, so it is unreasonable for the high level roadway to be 15 m away from the backwind lane. When the high level roadway is offset 10 m to the right from the air return roadway to 25 m, the concentration of gas extracted from the high level roadway has a large increase, which indicates that the high level roadway can extract a large concentration of gas at this location, and the extraction range is wide. As the horizontal

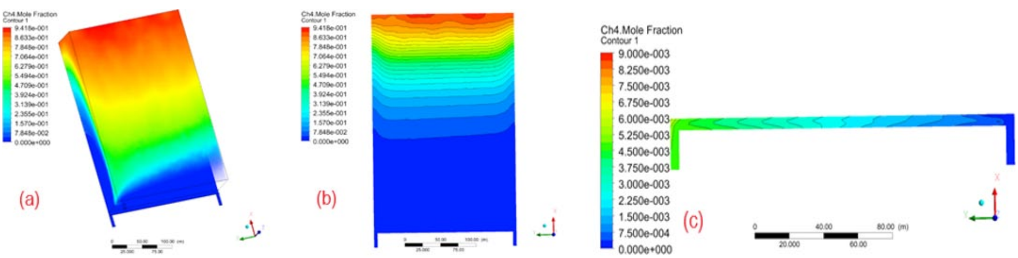

Fig. 8. Gas concentration distribution map at a horizontal distance of 15 m and a vertical height of 35 m in a high level roadway. (a) Stereoscopic plot of gas concentration distribution at a horizontal distance of 15 m, (b) Gas concentration slice plot at z = 1.7 m, (c) Mining face gas concentration slice plot

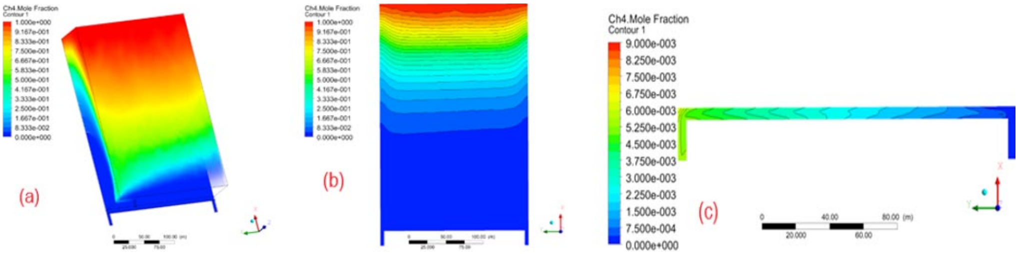

Fig. 9. Gas concentration distribution map at a horizontal distance of 35 m and a vertical height of 35 m in a high level roadway. (a) Stereoscopic plot of gas concentration distribution at a horizontal distance of 25 m, (b) Gas concentration slice plot at *z* = 1.7 m, (c) Mining face gas concentration slice plot

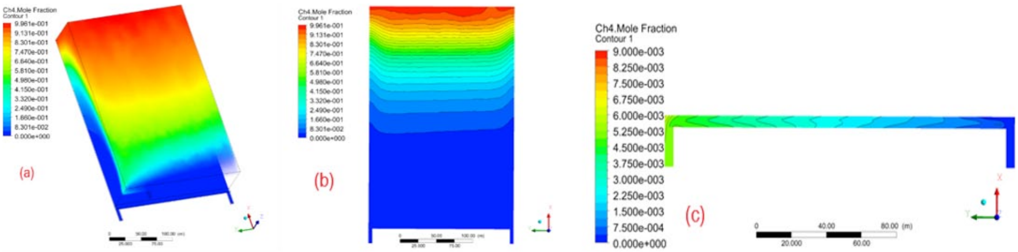

Fig. 10. Gas concentration distribution map at a horizontal distance of 45 m and a vertical height of 35 m in the high level roadway. (a) Stereogram of gas concentration distribution at a horizontal distance of 45 m, (b) Gas concentration slice plot at *z* = 1.7 m, (c) Mining face gas concentration slice plot

TABLE 3

The gas concentration of each roadway in mining face with different horizontal distance

Horizontal distance / m	Gas concentration in return air corner	High level roadway gas concentration
15	0.5716%	1.35%
25	0.58%	1.4%
35	0.611%	1.48%
45	0.63%	1.37%

distance continues to increase, when it reaches 45 m, the concentration of gas extracted from the high level roadway is decreasing, and the decrease is larger, which indicates that the effective area of gas concentration extracted from the high level roadway is shrinking. At the same time, with the increasing horizontal distance, the corner gas concentration on the working surface also increases. And the change of gas concentration in the upper corner is obvious, which indicates that under the same height, the increase of level distance mainly affects the gas concentration in the upper corner, but has less effect on the gas extraction concentration.

Through comparative analysis, it is obvious that the best location for the high level roadway is at 25 m from the air return roadway, which can ensure that the high level roadway extracts a large concentration of gas, but also ensure that the gas concentration in the upper corner is within the safe range, not exceeding 1%. Therefore, the best location for the high level roadway is 35 m from vertical and 25 m from flat.

4.3. Effect of different negative suction pressure on gas gushing from the gob

High negative suction pressure is important for gas prevention and control in return wind corner and return wind lane. To explore the effect of different negative suction pressure on the gas concentration of each lane, based on the field measurement, set the pressure difference between air intake roadway and air return roadway as 80 Pa, the location for high level roadway is 35 m vertical from the coal seam and 25 m flat from the air return roadway, and the under pressure of high level roadway as –8000 Pa~–13000 Pa respectively, as shown in Fig. 11 and Fig. 12, every 1000 Pa, simulated once, for a total of 6 times.

Based on the simulation results, the relevant data are summarized as shown in Table 4.

From a comprehensive point of view, the gas concentration in the return air corner, the high level roadway, and the gob will be affected by the negative pressure of extraction, with the increase of the negative suction pressure, the gas concentration in the return corner first decreases and then increases. This is because at the beginning of the negative suction pressure is large, the gas in the return corner and the return wind lane will be pumped into the high level roadway through the channel of the gob, presenting a decrease in gas concentration, and then as the negative suction pressure becomes large the stable state of the deep high concentration gas is disturbed and carried out by the wind flow, resulting in an increase in gas concentration in the upper corner. The gas in the gob is increased due to the negative pressure and the wind volume

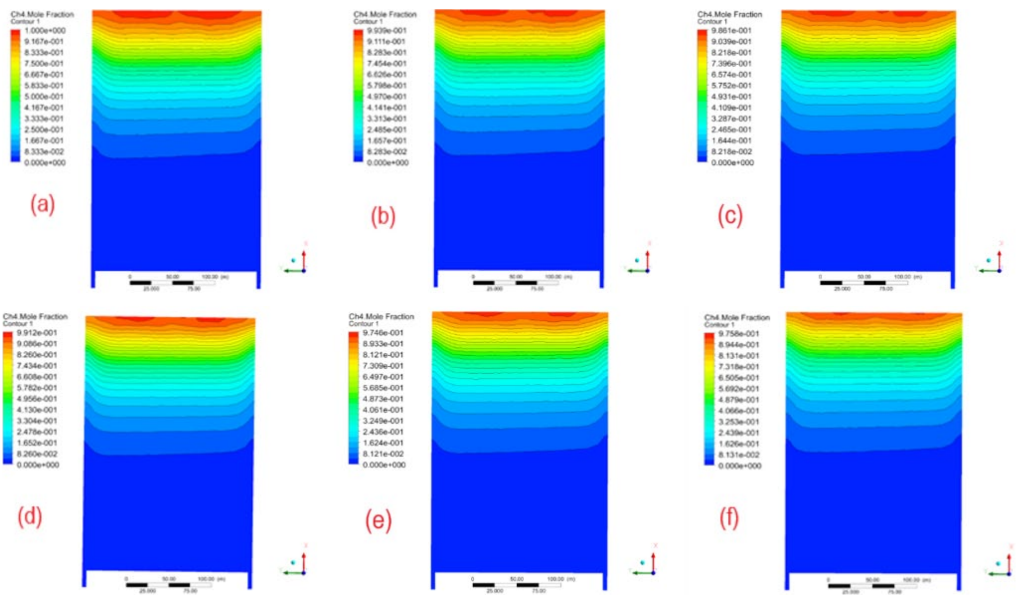

Fig. 11. Simulated distribution of XY-plane gas concentration under different negative suction pressure conditions. (a) 8000 Pa, (b) 9000 Pa, (c) 10000 Pa, (d) 11000 Pa, (e) 12000 Pa, (f) 13000 Pa

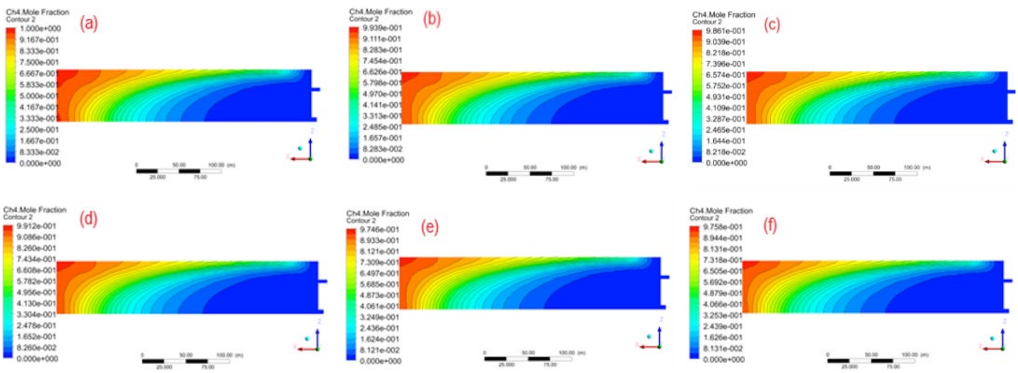

Fig. 12. Simulated distribution of YZ plane gas concentration under different negative suction pressure conditions. (a) 8000 Pa, (b) 9000 Pa, (c) 10000 Pa, (d) 11000 Pa, (e) 12000 Pa, (f) 13000 Pa

TABLE 4

Relationship between gas concentration in each roadway of mining face and negative pressure in high level roadway

Negative pressure/Pa	Gas concentration in return air corner	High level roadway gas concentration
–8000	0.58%	1.2%
–9000	0.54%	1.16%
–10000	0.541%	1.12%
–11000	0.551%	1.04%
–12000	0.561%	1%
–13000	0.563%	0.96%

becomes larger, resulting in the low concentration area of gas in the gob gradually deepening to the upper right of the extraction area, and the distribution range increases significantly. And the gas near the high level roadway will be diluted due to the increase of negative pressure and wind volume, although the total amount of extracted gas will increase, and the gas concentration in the high level roadway will be reduced.

Separately, the gas concentration in the corner of the return wind varies greatly when the negative suction pressure is 8000 Pa~9000 Pa, from 0.58% to 0.54%, but after the negative suction pressure exceeds 9000 Pa, the gas concentration in the upper corner shows an increasing trend, which indicates that the gas concentration in the corner of the return wind does not continue to decrease significantly under the condition of increasing the extraction cost by increasing the negative suction pressure, and it is important to find a suitable It is very important to find the suitable negative pressure for high pumping to control the gas concentration in the corner of the return wind and reduce the cost. According to the results of this simulation, the gas concentration in the return corner and air return roadway will not exceed the limit within the calculated negative suction pressure range, but the efficiency of gas extraction is not well improved by increasing the negative suction pressure. Proper negative suction pressure can reduce the extraction cost and prevent the gas from exceeding the limit. A comprehensive analysis recommends the design of negative suction pressure for high level roadway to be 9000 Pa~10000 Pa.

4.4. Simulation Validation

In order to verify the correctness of the simulation results, the high level roadway was set at a vertical distance of 35 m over the coal seam and the horizontal distance is 25 m from the air return roadway, and the negative suction pressure was designed to be 9500 Pa. Gas samples from the gob were collected by beam tube monitoring and analyzed by gas chromatography. There are 2 measuring points in the gob, 1 point is located in the upper corner of the return wind side and 1 point is located in the middle of the high level roadway. According to the progress of the mining face, the sampling time is 15 days, with a total of 15 samples, and the samples are taken regularly in the morning and analyzed in the afternoon every day.

Fig. 13 shows the trend of gas concentration changes in the gob sampled on site. It can be seen from the figure that the gas concentration in the return air corner under the action of high level roadway is basically maintained at 0.5%, and the gas concentration in the high level roadway is basically maintained at 1.2%. At each measurement point, the measured gas concentration is basically similar to the simulation results, and the gas concentration in the air return roadway will not exceed the limit. The research shows that the U+HLR ventilation method proposed in this paper has a more obvious effect on the gas management in the upper corner of the mining face.

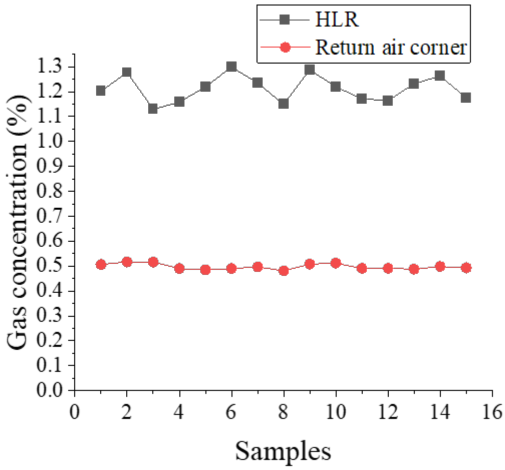

Fig. 13. Trend of gas concentration

5. Conclusion

In this paper, through a combination of theoretical analysis and numerical simulation, we studied the gas transport law of the mining face and the gob, determined the reasonable level of the high level roadway and the negative suction pressure, and came to the following conclusions:

(1) Through numerical simulation, it is found that U+HLR ventilation method has a more obvious effect on the gas management of corner angle on mining face, and the layer arrangement of high level roadway has an important influence on its gas management effect, by adjusting the layer relationship of high level roadway, it can effectively reduce

the gas concentration of middle and return corner angle and the gas concentration over the limit of return corner angle, and the best height is when the vertical distance of high level roadway is 35 m from the coal seam.

(2) After determining the optimal vertical distance of 35 m, the numerical simulation shows that the high level roadway at 25 m from the level distance of the return lane can extract a large concentration of gas, and the extraction range is wide. Therefore, the best location for the high level roadway is at 25 m from the return air roadway, which can ensure that the high level roadway can extract a large concentration of gas while ensuring the gas concentration in the upper corner is within the safe range.

(3) Appropriate high negative suction pressure can not only reduce the extraction cost, but also prevent the gas from exceeding the limit. In the range of –8000 Pa~–13000 Pa negative suction pressure, the gas concentration in the return corner and return tunnel will not exceed the limit, but the continuous increase of negative suction pressure does not improve the gas extraction efficiency well. The comprehensive analysis recommends that the design of negative suction pressure of high level roadway should be 9000 Pa~1000 Pa.

References

[1] Z.F. Wang, Discussion on modern coal mine safety management and countermeasures in the new era. Coal Engineering **51** (S2), 187-189 (2019).

[2] Y.G. He, W.G. Liu, Y.Q. Li, An overview of the development of the world coal industry. China Coal **47** (1), 126-135 (2021).

[3] J.W. Zhang, H.X. Yang, Statistical analysis of major and above accidents in coal mines in China from 2005-2019 and study of countermeasures for safety production. Coal Mine Safety **52** (12), 261-264 (2021).

[4] R.L. Wu, Theoretical study on the scope of "three zones" of gas unloading and extraction in coal seam group mining, China University of Mining and Technology (2011).

[5] Q.C. Li, X. Zhu, Z.G. Wang, Improved Darcy equation for coal seam permeability calculation. Science and Technology Innovation Herald **12** (23), 56-58 (2015).

[6] Y.P. Qin, Y.J. Hao, P. Liu, W. Liu, J. Wang, Numerical simulation of coal chip gas Fick diffusion. Journal of Liaoning University of Engineering and Technology (Natural Science Edition) **33** (7), 871-876 (2014).

[7] S. Zheng, Y.A. Wang, Z.Y. Wang, G.X. Chen, Gas extraction and utilization in Chinese coal mines. Coal Mine Safety **9**, 4-6 (2003).

[8] A. Mark, C. Luis, V. Alexis, Porous Medium Flow with Both a Fractional Potential Pressure and Fractional Time Derivative. Chinese Annals of Mathematics **38** (1), 45-82 (2017).

[9] P.D. Sun, Study of gas dynamics model. Coalfield Geology and Exploration **1**, 33-39 (1993).

[10] J.W. Cheng, X.R. Zheng, Y.D. Lei, A compound binder of coal dust wetting and suppression for coal pile. Process Safety and Environmental Protection **9** (31), 92-102 (2021).

[11] S. Zhu, J.W. Cheng, W.T. Song, Using seasonal temperature difference in underground surrounding rocks to cooling ventilation airflow: A conceptual model and simulation study. Energy Science & Engineering **8** (10), 3457-3475 (2020).

[12] J.W. Cheng, C. Qi, S.Y. Li, Modelling mine gas explosive pattern in underground mine gob and overlying strata. International Journal of Oil, Gas and Coal Technology **22** (4), (2019).

[13] L. Wang, Experimental and numerical simulation study of gas deflagration propagation law in large tunnel and small pipeline, Harbin Engineering University (2021).

[14] J.W. Cheng, Assessment of Mine Ventilation System Reliability Using Random Simulation Method, Environmental Engineering and Management Journal **5** (4), 841-850 (2016).