Numerical Simulation Study on the Effective Distance of Pressurized Ventilation in Gas Tunnel Construction

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Abstract: The ventilation of gas tunnel construction has always been a difficult point in the construction of gas tunnels, and the construction risk is high, and the ventilation cost is large. How to efficiently and quickly analyze the gas emission of different sections and take corresponding ventilation measures can improve the safety of gas tunnel construction and reduce the consumption of funds. Therefore, in this paper, the source term of gas emission is used to deal with it, and the actual pollution source is regarded as the source term in the air at a small distance from the wall of the tunnel face, and its emission is the actual emission of the tunnel gas source, and the source term S of these units is equal to the amount of gas generated per unit volume and unit time. Numerical simulation analysis can be carried out more vividly for the improvement of the construction safety of gas tunnels. In recent years, with the proposal of China's "double carbon" goal, the requirements for green construction have also been raised to a new height, and the ventilation standards for gas tunnel construction are getting higher and higher.

Keywords: Fluent; Gas Concentration Pressure Ventilation; Numerical Simulation

1. Introduction

With the continuous development of tunnel engineering, more and more tunnels encounter gas problems in construction. In the previous survey design, most of them chose to avoid the gas area as much as possible. However, with the development of the national road network and various constraints, tunnel construction has inevitably required to pass through the gas area [1], so the ventilation of gas tunnels has become an urgent problem to be solved. Therefore, based on a high-speed gas tunnel in Sichuan, this paper uses Fluent numerical simulation to analyze the gas migration law of the tunnel in different ventilation stages.

With the improvement of China's comprehensive strength, tunnel and underground engineering construction has developed rapidly in China in recent years. "Large quantity, large length, large buried depth, large cross-section" is the overall trend of the development of tunnel engineering in China and the world in the 21st century. The terrain in southwest China is complex, and there are a large number of mountains and rivers, and tunnels are usually used to cross when traffic lines pass through these terrains. When the railway tunnel passes through the gas formation, the surrounding rock is damaged by the force balance, which may lead to the gas gushing out, and the formation of the railway gas tunnel gas is a colorless and odorless toxic gas, which will cause the construction personnel to suffocate after reaching a certain concentration in the air, and even explode under the ignition condition, causing serious consequences. Strengthening ventilation during tunnel construction to avoid gas accumulation is an important means to avoid gas accidents in tunnel construction.

2. Engineering Geology

The tunnel is located at the junction of two counties in Sichuan Province and is distributed in a north-west direction. The mountain is thick, the highest altitude is about 4000m, the north and south slopes are developed to the valley, the altitude above 2000m is generally V-shaped, the ditch wall is steep, the valley bottom is narrow, the valley slope is steep, and the general slope is greater than 35°. The tunnel site area is a tectonic denudation high and high mountain landform, with large undulating terrain in the cave body, high in the middle, and relatively low in the inlet and outlet sections. The altitude is 2329m~3400m, the relative height difference is about 1100m, the local steep cliff shape, the maximum buried depth of the tunnel is 1092m, which belongs to the cross-ridge tunnel. The tunnel passes through non-coal measure strata such as slate, carbonaceous slate, sandstone, granite porphyry, etc., and the gas comes from the oil-type gas produced during the carbonaceous slate diagenesis and the inorganic gas formed by the metamorphism of the surrounding rock mass and magmatic incursion, which mainly exists in the slate and sandstone in the adsorption state and free state. Faults, joints and other structures are very well developed and are the main channels for gas migration.

3. Mathematical Model Building

3.1 Basic Assumptions

Because the ventilation airflow in this tunnel is a low-velocity gas, it can be regarded as an incompressible fluid; At the same time, the friction force and the heat dissipation energy that may be generated by the fluid movement in the tunnel are ignored, and the tunnel wall cannot transmit heat and conduct, and the energy cannot be transmitted, and the gas does not undergo any chemical reaction and corresponding reaction in the diffusion movement, so the fluid field can be regarded as constant temperature and the wall surface is isothermal[2-7]; The airflow in the tunnel has an isotropic turbulent viscosity, and the dynamic viscosity coefficient of the tunnel is treated as a scalar. The airflow in the tunnel is regarded as steady-state turbulence; There are no other sources of gas gushing and pollutant release in the tunnel, and the gas gushes out uniformly from the tunnel face; The velocity of the air jet from the air duct mouth is evenly distributed.

3.2 Governing Equations

The movement of air in the tunnel can be regarded as turbulence, and the movement process of gas in the tunnel mainly includes the diffusion of gas gas, the convection of gas and air, and the turbulence of gas and air. Since the density of air is higher than that of gas, the mixed movement of air and gas in the tunnel will inevitably cause the density of the air flow in the whole tunnel to change. At the same time, because the airflow near the face of the gas gushing source is mainly gas gas, the airflow density in this area is bound to be lower than that of the surrounding gas-air mixture, so the influence of buoyancy should also be considered. The volumetric force caused by the uneven movement of air currents of different densities in a fluid under the action of gravity is the buoyancy force. In this study, it is assumed that the gas in the tunnel is emitted from the tunnel face, and the source term setting is selected to deal with the gas source, and the turbulence model and component transport model are selected to simulate the airflow field and the movement and distribution of gas in the tunnel. The governing equations of turbulent diffusion and migration of air and gas include component transport equations, momentum conservation equations, and mass conservation equations. The turbulence model is the standard k-e two-equation model of the turbulent viscous coefficient method in the Reynolds average method, and the standard wall function method is used for the gas flow near the wall.

Based on the above assumptions and setting conditions, the governing equations for steady-state air flow and gas turbulent flow in a tunnel can be expressed in the form of a general differential equation:

$$\frac{\partial(\rho u\phi)}{\partial x}+\frac{\partial(\rho v\phi)}{\partial y}+\frac{\partial(\rho w\phi)}{\partial z}=\frac{\partial}{\partial x}\left(\Gamma_\phi\frac{\partial\phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(\Gamma_\phi\frac{\partial\phi}{\partial y}\right)+\frac{\partial}{\partial z}\left(\Gamma_\phi\frac{\partial\phi}{\partial z}\right)+S_\phi \tag{1}$$

where u, v, and m are the velocity components in the x, y, and z directions, respectively; The protection can be expressed according to different models, such as velocity, component mass fraction, turbulent flow energy dissipation rate, turbulent flow energy; Γ_ϕ is the ϕ corresponding diffusion coefficient; S_ϕ is the ϕ corresponding source item[8-10].

3.3 Physical Models

According to the actual size of the tunnel project, the model setting is simplified, and the two-dimensional tunnel model is established by software, as shown in Figure 1, and the model is meshed by software.

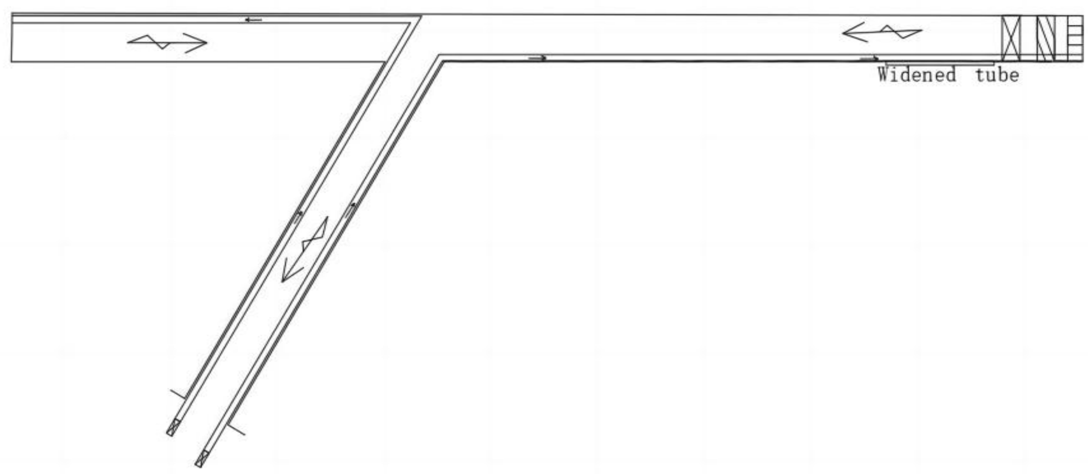


Figure 1. Two-Dimensional Physical Model

3.4 Parameter Selection Settings

Through the analysis of various parameters of the tunnel and the comparison of the simulation results obtained by applying different parameters, the parameters are continuously adjusted and optimized, and the conventional numerical model for simulating the gas diffusion of the tunnel is determined.

(1) Inlet boundary: The ventilation nozzle is set as the velocity inlet boundary, and the wind flow enters the tunnel uniformly along the direction of the vertical thousand wind pipe mouth, and the wind flow is evenly distributed, the wind speed v, and the O_2 content in the air flow is 21%.

(2) Exit boundary: The tunnel exit is set as the free flow boundary.

(3) Wall boundary: all wall surfaces such as tunnel surface and side wall in the tunnel are regarded as fixed wall surfaces, and are regarded as non-slip boundary conditions, and the standard wall function method is selected to deal with the near-wall surface, and all wall surfaces are regarded as adiabatic.

(4) Gas source term: In this paper, the gas emission is treated by the source term, and the actual pollution source is regarded as the source term in the air at a small distance from the wall of the tunnel face, and the emission is the actual emission of the tunnel gas source, and the source term S of these units is equal to the amount of gas generated per unit volume and unit time[11,12].

4. The Study of Gas Migration Law in Different Ventilation Stages of Tunnel Branch Tunnels in This Study

4.1 Single-Head Press-in Ventilation

The gas emission of the tunnel face is set to 1.244m3/min, and the air pressure of the press-in fan is set to 4000Pa. The schematic diagram of the model settings is as follows Figure 2:

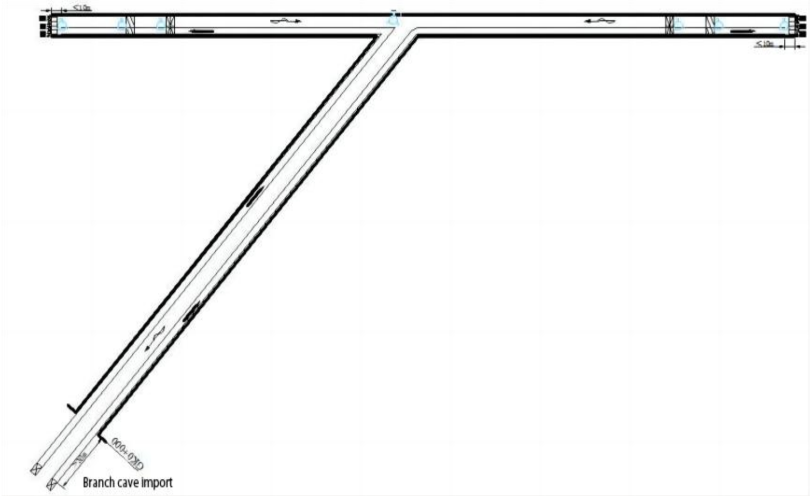


Figure 2. Schematic Diagram of the Model Settings

4.1.1 The main tunnel is excavated 500m

Under the condition of single-head press-in ventilation, when the main tunnel is excavated for 500m, the velocity vector diagram, velocity contour diagram and gas concentration distribution diagram obtained by Fluent software are shown in Figure 3, Figure 4 and Figure 5, respectively.

Figure 3-Figure 5 are the velocity vector diagram, velocity distribution diagram and gas distribution diagram inside the tunnel excavation to 500m. As can be seen from the Figure 3~5, under the condition of single-head press-in ventilation, the two air ducts in the branch tunnel are connected to the vicinity of the left and right two tunnel faces. It can be seen from the velocity vector diagram that the wind flow is introduced into the tunnel from the duct and reaches the left and right two tunnel faces, although there is gas gushing out from the tunnel face, but due to the large air volume, the gas gas on the tunnel face is diluted, and at the same time, due to the limitation of the tunnel face and the continuity of the wind flow, there is a flow wind flow opposite to the direction of the jet backflow, so that the gas gathers on the walls on both sides of the tunnel, so that the gas concentration at the place is significantly increased, and the gas concentration on the side of the duct is significantly lower than that on the other side of the duct, and the area with the largest gas concentration appears in the reflux area. It can be seen from the wind speed distribution diagram that when the excavation reaches 500m, due to the single-head press-in ventilation condition, the outlet wind speed is the minimum wind speed of the whole tunnel, while in Figure 4, the minimum wind speed is 0.41m/s, which is greater than 0.25m/s, which meets the ventilation conditions, and in Figure 5, due to the dilution of wind flow, the maximum gas concentration near the tunnel face is 0.27%, less than 0.5%, which meets the construction safety requirements.

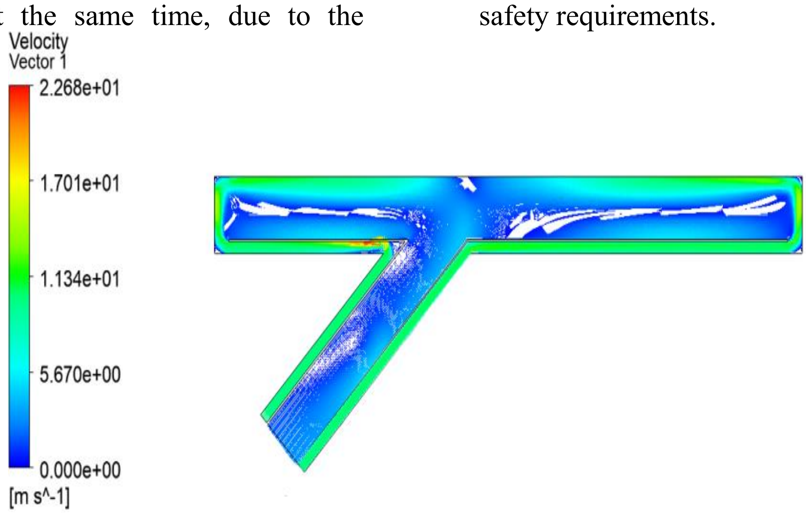


Figure 3. Vector Diagram of Velocity at 500m

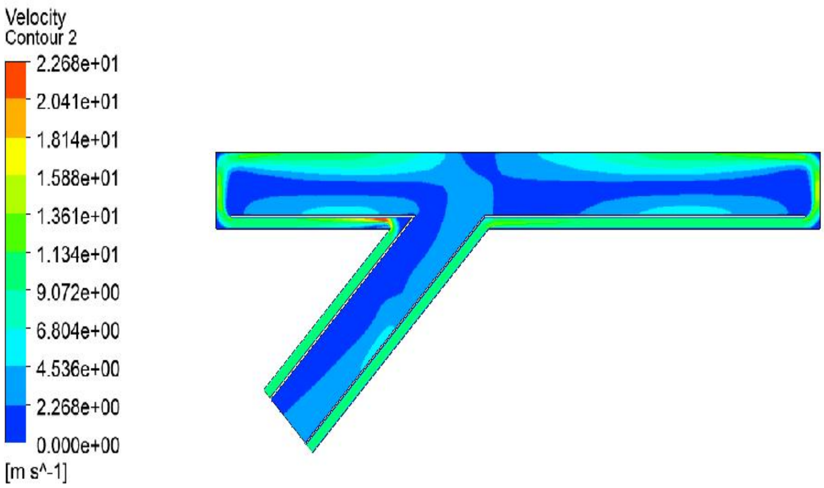
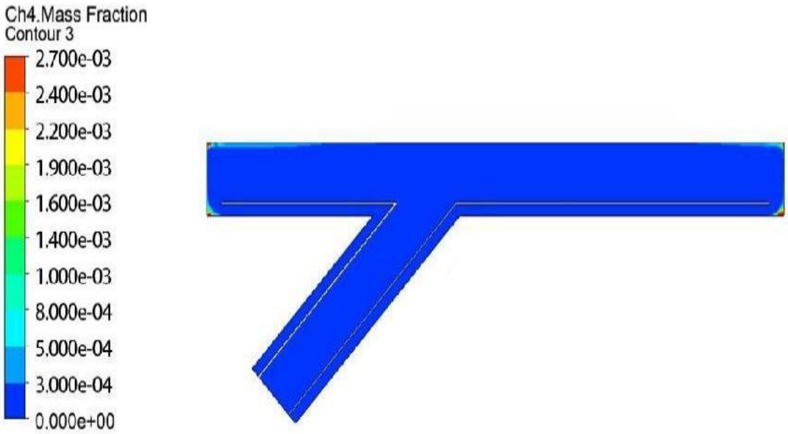
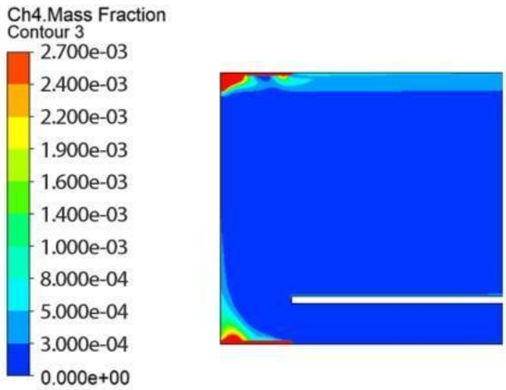


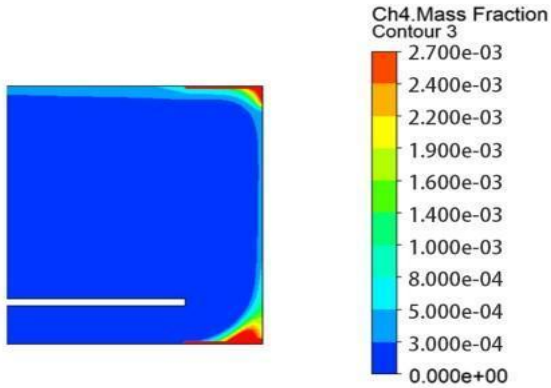
Figure 4. Velocity Distribution Diagram of Excavation at 500m



(a)The Overall Gas Distribution in the Tunnel When Excavation is 500m



(b) Gas Distribution Map of the Left Tunnel Face



(c) Gas Distribution Contour of the Right Tunnel Face

Figure 5. Diagram of Gas Distribution in the Tunnel during Excavation of 500m

4.1.2 The main tunnel is excavated for 1000m

When the tunnel is excavated to 500m, the wind speed and gas concentration requirements are met in the tunnel, and the tunnel face continues to advance, Figure 6~Figure 8 is the internal velocity vector diagram, the wind speed distribution cloud map and the gas distribution cloud map in the tunnel when the tunnel is excavated to 1000m. As shown in Figure 5-Figure 8, when the tunnel is excavated to 1000m, the wind speed and gas concentration distribution in the tunnel are quite different from those at 500m, due to the increase in the length of the tunnel, the wind speed near the air outlet side of the tunnel will decrease significantly, as shown in Figure 7, the wind flow speed on the side of the air outlet at the tunnel exit is 0.36m/s, which is lower than that of 500m, but still meets the ventilation requirements of the low-gas tunnel, which is greater than 0.25m/s; As can be seen in Figure 8, the gas concentration on the left and right faces decreases due to the decrease in air volume, so the gas concentration increases, but the maximum value is 0.39%, less than 0.5%, which also meets the construction safety requirements.

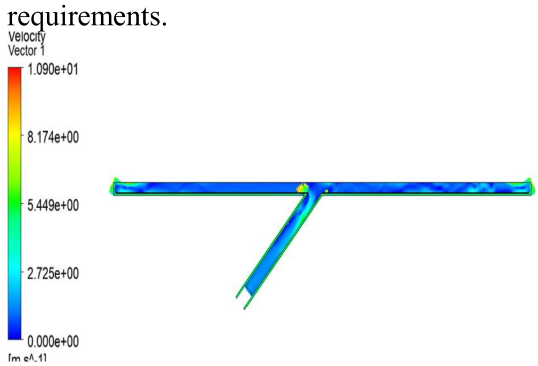


Figure 6. Vector Diagram of Velocity at 1000m

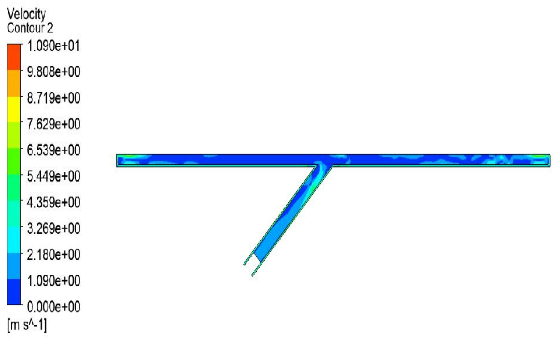
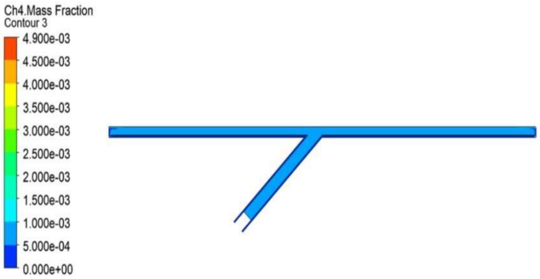
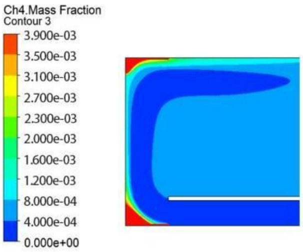


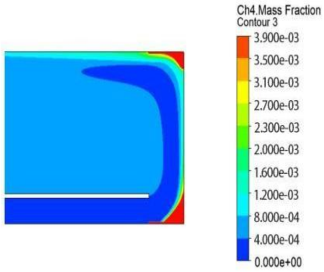
Figure 7. Wind Speed Distribution Diagram during Excavation of 1000m



(a)The Overall Gas Distribution Cloud Map in the Tunnel When Excavating 1000m



(b) Gas Distribution Map of the Left Tunnel Face



(c) Gas Distribution Contour of the Right Tunnel Face

Figure 8. Diagram of Gas Distribution in the Tunnel When Excavation of 1000m

4.1.3 The main tunnel excavation is 1500m

When the tunnel is excavated to 500m and 1000m, the wind speed and gas concentration requirements are met in the tunnel, and the tunnel face continues to advance, Figure 9 ~ Figure 11 are the internal velocity vector diagram, wind speed distribution cloud map and tunnel gas distribution cloud map when the tunnel is excavated to 1500m.

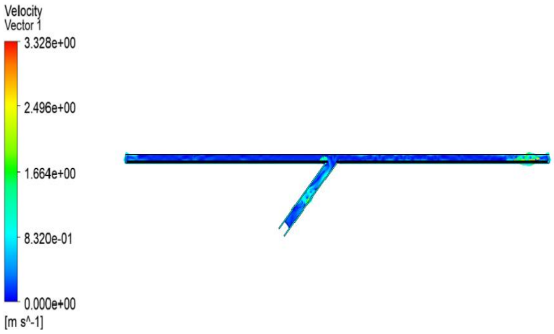


Figure 9. Vector Diagram of Velocity at 1500 m

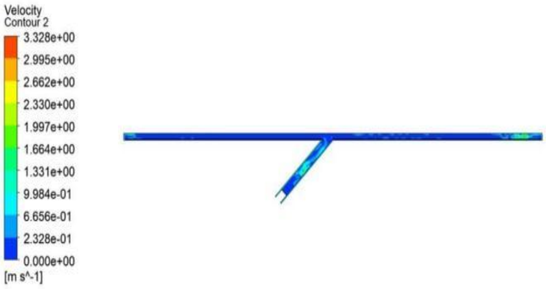
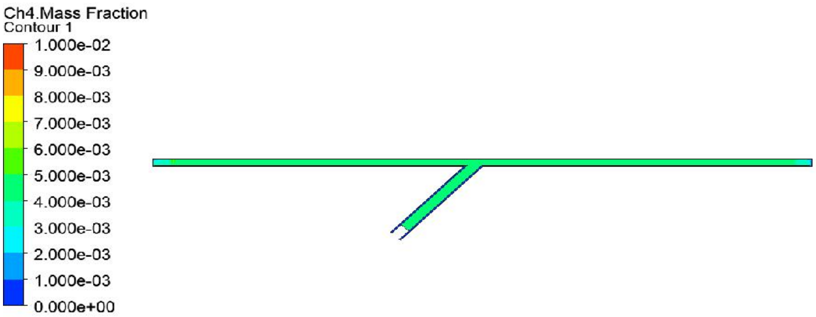
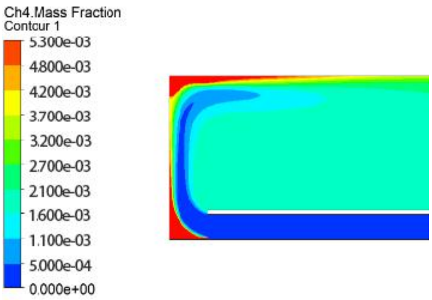
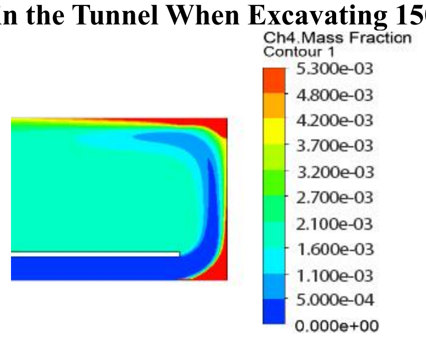


Figure 10. Wind Speed Distribution Diagram When Excavation is 1500 m



(a)The Overall Gas Distribution Cloud Map in the Tunnel When Excavating 1500m





(b) Gas Distribution Map of the Left Tunnel Face (c) Gas Distribution Contour of the Right Tunnel Face

Figure11. Diagram of Gas Distribution in the Tunnel during Excavation of 1500m

As shown in Figure 9-Figure 11, when the tunnel continues to excavate to 1500m, the wind speed and gas concentration will also change, due to the lengthening of the distance, the wind speed is greatly reduced compared with 500m and 1000m, and the wind speed at the air outlet of the tunnel entrance is 0.23m/s, less than 0.25m/s, which can not meet the ventilation requirements; As can be seen from Figure 11, the gas concentration increases when the wind speed changes, and the gas concentration reaches 0.53% on the left and right faces, which is greater than 0.5%, which cannot meet the construction safety requirements.

5 Conclusion

Therefore, under the condition of single-head press-in ventilation, when the excavation of the tunnel face is 500m and 1000m, the wind speed and the gas concentration of the tunnel face can be better met, but with the distance becomes longer, when the tunnel face is excavated to 1500m, the wind speed and the gas concentration of the tunnel face can not meet the construction requirements. At this time, due to the advance design, the ventilation method was replaced, and the roadway ventilation was adopted. Through Fluent numerical simulation, the distribution of gas in different stages of the tunnel can be efficiently and quickly analyzed, and the ventilation requirements can be accurately and effectively analyzed, and the safety of gas tunnel construction can be improved.

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