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Research on Ventilation Simulation Technology for Large Section Gas Tunnel Construction



Abstract: - In order to solve the problem of gas overrun during the construction of large section gas tunnel, this paper takes the Baima Tunnel as the engineering background and uses fluent numerical simulation software to study the gas transport law of the tunnel under different ventilation methods. The results indicate that when the tunnel is excavated for 1200m, the forced ventilation method cannot effectively solve the problem of gas overrun on the heading face. After adopting the gallery ventilation method, the gas concentration on the heading face decreases to less than 1%, which effectively solved the problem of gas overrun on the heading face and provided assistance for the safe construction of the project..

Keywords: large section tunnel; gas overrun; numerical simulation; entilation methods.

I. INTRODUCTION

With the rapid development of national economy, China's transportation industry is also developing rapidly. The number and mileage of tunnel construction in mountainous and hilly areas are constantly increasing. The majority of the gas tunnels built before 2000 were low-gas tunnels, while the number and length of high-gas tunnels increased significantly after 2000[1-3]. However, with the increase of gas quantity and the destruction of coal and rock, the incidence of gas accidents also increased, and the gas problem became one of the main problems in underground engineering construction in central and western China[4-5]. Therefore, many scholars at home and abroad have done a lot of research on tunnel gas prevention and control and have achieved certain results. Yan et al.[6] studied the prevention and control of gas hazards in a tunnel under construction. Zhang et al.[7] studied the regularity of gas emission and diffusion at tunnel face during tunnel construction. Some scholars studied that comprehensive exploration should be conducted using geological mapping, gas monitoring, and other methods to analyze the source of gas and predict the gas in the unexcavated surrounding rock[8-9]. Liu et al.[10] studied the influence of air duct layout on gas concentration in large section gas tunnel. In Wu's study[11], Analyzed the source term estimation of natural gas leakage in utility tunnel by combining CFD and Bayesian inference method. Li Studied[12] the ventilation simulation of high gas long tunnel construction.

This article established a mathematical model for ventilation during the construction of a large section gas tunnel, analyzed the different ventilation methods of the gas tunnel, and takes the Baima gas tunnel as an example to simulate and analyze the migration and distribution of gas in the airflow field using Fluent numerical simulation. The general characteristics of the airflow field and gas distribution in the gas tunnel under different ventilation methods are obtained, which provided reliable theoretical basis and technical support for taking reasonable measures to prevent gas overrun.

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II. PROJECT OVERVIEW

Baima extra long tunnel is located in Punan Village, Wujiao Township, Jiuzhaigou County, Sichuan Province, with a total length of 13013m. The Baima Tunnel is designed as a two-way six lane tunnel with a wide boundary for a single tunnel building×Height (m)=14.5×5m. The terrain of the tunnel body is high in the middle, with significant undulations. The terrain of the entrance and exit sections is relatively low, with an elevation of 2329-3400 meters and a relative elevation difference of about 1100 meters. It is a tectonic eroded high and medium mountain landform. The average absolute gas emission of working face is 1.253m³/min.

III. CALCULATION OF VENTILATION VOLUME IN TUNNEL CONSTRUCTION

A. Standard for Air Volume Design and Calculation

According to the specifications and related ventilation quality requirements, the absolute emission of gas, the maximum number of people required to work at the same time, the air volume required for internal combustion engine operation, the air volume required for blasting smoke exhaust, and the air return volume of gallery are calculated.

B. Internal Combustion Machinery Needs Air Volume

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The internal combustion equipment working at the same time in the tunnel is the most in the upper loading and secondary lining, and the air volume is the largest. Therefore, the main equipment is loader, slag transport vehicle, excavator and concrete transport tank truck.

Internal combustion machinery needs air volume:

$$Q_1 = \sum_{i=1}^N kT_i N_i = 2831.4 \text{ m}^3 / \text{min} \quad (1)$$

Where: Q₁ is the air demand of internal combustion machinery, m³/min; k is the calculation coefficient of power ventilation, and the provisions are 2.8~3.0; N is the total number of internal combustion machinery; N_i is the provisional power of each diesel equipment; T_i is the operating utilization coefficient of each internal combustion engine equipment.

C. Air Volume Required for Discharging Cannon Smoke

$$Q_2 = \frac{2.25}{t} \times \sqrt[3]{\frac{G(A \times L)^2 \psi b}{P^2}} = \frac{2.25}{20} \times \sqrt[3]{\frac{168 \times (170 \times 10.03)^2 \times 0.8 \times 100}{2.27^2}} = 221.022 \text{ m}^3 / \text{min} \quad (2)$$

Where: Q₂ is the air volume required for discharging cannon smoke, m³/min; G is the amount of explosive in simultaneous blasting (kg), G=168kg according to the site situation; A is the sectional area of the gallery, m², A=170m²; L is the gallery length or critical length, m; ψ = 0.8; b is the harmful gas generated during explosive explosion, and b=100 is taken by blasting in coal seam; t is the ventilation time in the cave, t=20min; P is the air leakage coefficient of the air duct, and the air leakage rate of 100 meters is P100=2%.

D. Air Volume Required to Maintain Minimum Dust Removal Speed

$$Q_3 = vS = 15 \times 170 = 2550 \text{ m}^3 / \text{min} \quad (3)$$

Where: S is the tunnel sectional area; v is the dust exhaust speed, v=0.25m/s=15m/min.

E. The Staff Needs Air Volume

$$Q_4 = nq = 50 \times 4 = 200 \text{ m}^3 / \text{min} \quad (4)$$

Where: q is the air supply per person per minute in the gas tunnel, q=4m³/min; n indicates the number of people working in the tunnel at the same time, n=50.

F. Air Volume Required To Dilute Gas

When determining the ventilation volume required for gas dilution, it is necessary to conduct a gas drilling survey in advance to estimate the amount of gas occurrence and work out the ventilation volume to reduce the gas concentration below the allowable concentration.

$$Q_5 = \frac{V}{M} \times 2 = \frac{1.25}{1\%} \times 2 = 250m^3 / \text{min} \quad (5)$$

Where: Q_5 is the ventilation volume required by dilution gas, m^3/min ; V is gas emission ($0.99m^3/\text{min}$).

G Determination of Calculated Air Volume in the Tunnel

Through calculation and comparison, the maximum air volume is required in the tunnel for the simultaneous construction of the ballast on the upper step and the secondary lining. The total ventilation volume in the tunnel is:

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 = 6052.42m^3 / \text{min} \quad (6)$$

IV. DESIGN OF CONSTRUCTION VENTILATION SCHEME

A Purpose of Ventilation

The purpose of ventilation in the construction stage of high gas tunnel is as follows: (1) Dilute the concentration of gas and harmful gases, such as excavator, loader, transport vehicle exhaust gas, smoke, et al. (2) Lower the temperature; (3) Provide fresh air (mainly oxygen).

B The Choice of Ventilation Mode

In the tunnel ventilation, the ventilation modes were divided into forced ventilation and gallery ventilation. When the excavation is 1200m, the actual effects of the two ventilation modes are compared, so as to select the best ventilation mode.

C Division of Ventilation Stages

The tunnel ventilation is divided into two ventilation stages: forced ventilation and gallery ventilation.

- (1) The first stage: forced ventilation
- (2) The second stage: gallery ventilation

V. NUMERICAL SIMULATION RESULTS

A Model Building

1) Establishment of geometric model

(1) forced ventilation model

According to the actual situation of Baima Tunnel, under the condition of forced ventilation, there is only one air duct in the tunnel, which continuously blows fresh air flow from the outside of the tunnel into the inside of the tunnel, so as to dilute the gas in the tunnel and discharge the gas from the tunnel. The Model was established by using the Design Model module of Fluent software.

(2) gallery ventilation model

Under the condition of gallery ventilation, there are two air ducts in the left tunnel, one is the exhaust duct of the left tunnel, and the other is connected to the right tunnel through the cross passage to exhaust the right tunnel. Gallery ventilation can effectively solve the problem of gas overrun when the tunnel excavation length becomes larger, and make up for the deficiency of forced ventilation mode.

2) Basic assumption

- (1) Gas is considered incompressible.
- (2) The disturbance of human and mechanical flow field are ignored.
- (3) The tunnel wall is smooth.

3) Boundary condition

The outlet of the air duct was set as the entrance boundary. It was assumed that the fresh air flow uniformly entered the tunnel from the air duct opening, and the air flow direction was perpendicular to the air duct opening. The air flow velocity was set at 15m/s, and the oxygen content was set at 0.21. The tunnel outlet was set as a free flow boundary so that the fluid can flow out freely. At the same time, the wall was assumed to be an adiabatic wall, and the standard wall function method was used to deal with the air flow near the wall. Generally, there is

a certain roughness of the tunnel wall surface, and its influence on the tunnel ventilation cannot be ignored. Therefore, the tunnel wall roughness height R_h was set as 0.09. The roughness constant R_c was set as 0.55.

B Gas Distribution Law in Tunnel

1) Gas distribution law under forced ventilation

When gas is freely distributed in the tunnel space, the diffusion of gas concentration in the whole tunnel is analyzed. The axial plane of the tunnel was selected to analyze the gas distribution rule under the forced ventilation condition. When the wind speed at the inlet of the air duct was 15m/s and the tunnel was driven to 1200m, the distribution of gas concentration on the axial surface of the tunnel and the distribution curve of gas concentration on each section of the tunnel were shown in Figure 1. and Figure 2.

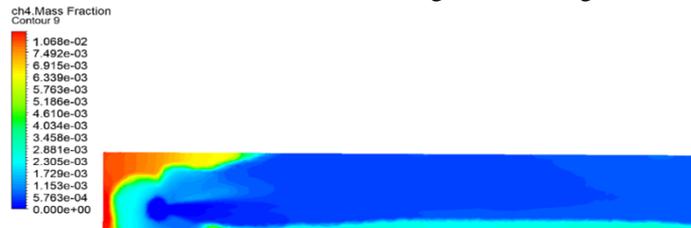


Figure 1. Gas concentration distribution map of axial surface under forced ventilation

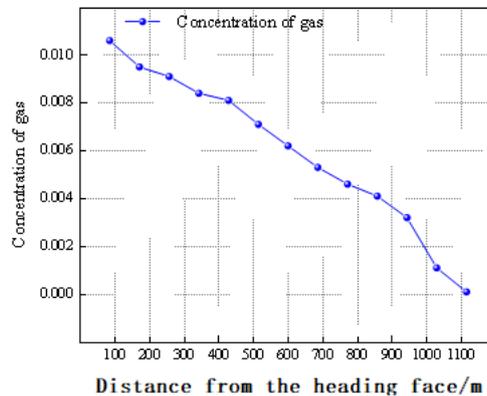


Figure 2. Gas distribution curves in each section under forced ventilation

When the tunnel was driven to 1200m, as the length of the tunnel was increased, the velocity of air flow into the tunnel will gradually decrease. Therefore, under the condition of forced ventilation, the concentration of gas near the heading face will continue to increase. As shown in Figure 1 and Figure 2, when the tunnel is driven for 1200m, the gas concentration in the tunnel increases significantly. Near the heading face of the tunnel, the gas concentration reached 1.068%, and the gas distribution ranged in the whole tunnel was 0.01%~1.068%. Because forced ventilation has obvious defects when the tunnel was driven up to 1200m (the deeper the tunnel excavation, the smaller the internal air flow), and causes gas overrun (greater than 1%). Therefore, other ventilation methods need to be selected to better dilute the gas on the heading face until the construction conditions were met.

2) Gas distribution law under gallery ventilation

In order to make up for the shortage of forced ventilation, gallery ventilation was adopted. Two air ducts, one for ventilation in the left tunnel and the other for ventilation in the right tunnel through a cross passage, were used for tunnel ventilation. When the tunneling was 1200m and the wind speed at the entrance of the duct was 15m/s, The gas concentration distribution at the axial plane of the tunnel and the gas concentration distribution curves at each section of the tunnel were shown in Figure 3. and Figure 4.

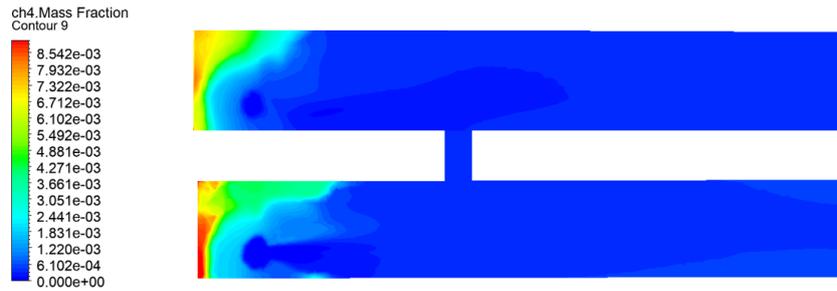


Figure 3. Gas concentration distribution map of axial surface under gallery ventilation

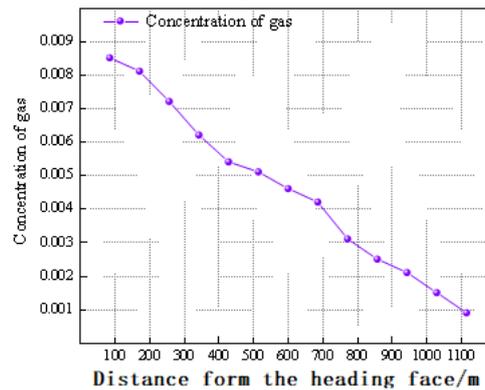


Figure 4. Gas distribution curves in each section under gallery ventilation

When the tunnel was driven to 1200m, the gallery ventilation has obvious advantages. As could be seen from Figure 3 and Figure 4, the gas concentration distribution was significantly lower than forced ventilation. Near the left and right heading face, the maximum gas concentration was 0.854% and 0.793% respectively, and the concentration range of the whole tunnel was 0.1%~0.854%. The advantage of gallery ventilation can reduce the gas concentration to less than 1%, which meets the conditions of tunnel construction.

VI CONCLUSION

- (1) The air volume was calculated based on the tunnel construction situation, which provides effective parameters for numerical simulation.
- (2) When the tunnel was driven to 1200m, the forced ventilation cannot meet the ventilation requirements, and the gas concentration of heading face in the tunnel increases significantly. The maximum gas concentration near the heading face was 1.068%, which cannot meet the construction safety requirements.
- (3) When the tunnel was driven to 1200m, the gas concentration of the tunnel was diluted to less than 1% by the gallery ventilation. The maximum gas concentration near the heading face of the two tunnels was 0.854% and 0.793%, both of which meet the construction requirements. It provides a reasonable and effective ventilation method for the large section gas tunnel.

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REFERENCES

- [1] Kang X B, Luo S, Li Q S, Xu M, Li Q. Developing a risk assessment system for gas tunnel disasters in China. *Journal of Mountain Science*. 2017; 14:1751-1762.
- [2] Wang H Y, Zhao S L, Liu J L, Zhou Y M, Chen X, Wang J, Cheng L. Prediction and analysis of abnormal gas emission law in low-gas tunnel based on K-Line diagram. *Geofluids*. 2020; 2020:8898394.
- [3] Hariana, Adi P, Ganda A, Arif D. Ash Evaluation of Indonesian Coal Blending for Pulverized Coal-Fired Boilers. *Journal of Combustion (Hindawi)*. 2021; 2021:8478739.
- [4] Muhammad A, Wang E Y, Li Z H, Jia H S, Li D X, Izhar M J, Barkat U. Study on Acoustic Emission Characteristics and Mechanical Behavior of Water-Saturated Coal. *Geofluids (Hindawi)*. 2021; 2021:5247988.
- [5] Liu Y M, Peng C, Yuan Q W, Chen H Y. Chemical evolution process and quality assessment of seepage groundwater in tunnel crossing gas-bearing coal seams. *Geofluids*. 2022; 2022:8524932.
- [6] Yan Q X, Yang K, Wu W. Prevention and control of gas hazards in a tunnel under construction. *Environmental Earth Sciences*. 2020; 79: 317- 333.

- [7] Zhang X J, Fang Y, Peng P. Study on regularity of gas emission and diffusion at tunnel face during tunnel construction. *Journal of Highway and Transportation Research and Development*. 2015;32 : 119-126.
- [8] Yao Y Z, He K, Peng M, Shi L, Cheng X D, Zhang H P. Maximum gas temperature rise beneath the ceiling in a portals-sealed tunnel fire. *Tunnelling and Underground Space Technology*. 2018; 80:10-15.
- [9] Zhang J H, Dong Y, Chen Y D, Sun H S, Wu J K, Liu W L, Chen J R, Pan S Q. Numerical simulation of gas ventilation mode in highway gas tunnel. *Geofluids (Hindawi)*. 2021; 2021:5549168.
- [10] Liu C, Du J S, Guo C Y. Influence of air duct layout on gas concentration in large section gas tunnel. *Modern Tunneling Technology*, 2019; 56: 114-121.
- [11] Wu J S, Liu Z, Yuan S Q, Cai J T, Hu X F. Source term estimation of natural gas leakage in utility tunnel by combining CFD and Bayesian inference method. *Journal of Loss Prevention in the Process Industries*. 2021; 68:104328.
- [12] Li Z W. Study on ventilation simulation of high gas long tunnel construction. *Energy and Environmental Protection*, 2020; 42: 81-85.