Study on oxygen concentration distribution of Sejila mountain tunnel construction based on fluent

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Abstract. Sichuan-Tibet Railway is a major construction project to ensure national defense security and support social and economic development in the west. Due to the geographical environment at high altitudes in the Sichuan-Tibet region, for every 1000 m increase in the average altitude, the atmospheric pressure decreases by about 11.55 %, and the oxygen partial pressure decreases accordingly, forming a low-pressure and low-oxygen environment, which affects the construction safety. The oxygen consumption of mechanical equipment in the tunnel and the discharge of pollutants make the construction personnel’s hypoxia problem more serious. Based on the project of the Sejila Mountain Tunnel, this paper divides the tunnel into the working face and the construction section along the tunnel according to different construction procedures. Based on the numerical simulation by CFD software, the distribution law of oxygen concentration in the tunnel construction process before the implementation of the environmental control scheme under different factors is proposed, and the relationship between various influencing factors and oxygen concentration distribution is obtained. It is concluded that oxygen consumption and emission of internal combustion engines and tunnel excavation length are important factors affecting oxygen concentration in the tunnel construction environment.

Keywords: Sichuan-Tibet Railway, high altitude, numerical simulation, tunnel construction

1 Project summary

The Sejila Mountain Long Tunnel is in Nyingchi City, Tibet Autonomous Region. It is designed as two single-track tunnels with a total length of 38 kilometers. The whole tunnel set 2 inclined Wells, and 1 cross hole to assist construction. The horseshoe section is adopted in the construction of the Sejila Mountain tunnel. The maximum span of the section is 7.97m in width and 7.52m in height. The construction area of the tunnel is in the altitude range of 4400 ~ 4700m, the plateau oxygen is scarce, the natural environment is harsh, and the number of construction personnel is huge. It is a representative extra-long tunnel in the Sichuan-Tibet railway tunnel. According to the statistics of meteorological data of Lulang Station, Sejila Mountain Peak Station and Linzhi Station, the annual average temperature in the tunnel site area is 0.1 – 9.6 °C, and the average temperature in the coldest month is −9.2 – −2.4 °C; and the average temperature in the hottest month is 6.7 – 20.6 °C[1].

2 Overview of tunnel construction

The entrance section of the Sejila Mountain Tunnel is mainly a TBM construction section, including an open-cut section at the entrance, a drilling and blasting section, and a drilling and blasting construction section of the TBM disassembly tunnel. In tunnel construction, diesel is the main fuel of the mechanical internal combustion engine. This paper mainly studies the oxygen content. Therefore, the molecular ratio of carbon, hydrogen, and oxygen in diesel is approximately 17:30:1 for approximate combustion, and other components can be ignored in the calculation[2]. According to the formula, diesel combustion needs to consume 24mol oxygen for each 1mol fuel. The emission law of tunnel internal combustion engine in high altitude area is investigated. The proportion of other pollutant emissions is still small relative to carbon dioxide, so the oxygen consumption mechanism of the internal combustion engine is similar to complete combustion.

The calculated oxygen consumption in the personnel concentration area is about 2.5 L / h, which is negligible relative to the internal combustion engine. According to the statistics on diesel consumption of the internal combustion engine, the average calculation results show that the fuel consumption of the internal combustion engine is 0.39 L / kwh, and the density of diesel is about 0.810 kg / L – 0.855 kg / L. In this paper, the oxygen environment of the tunnel in the construction section of the drilling and blasting method in Sejila Mountain is simulated, which is mainly divided into the...
excavation operation line, the loading operation line, the support operation line, the inspection and paving bottom operation line, the waterproof and drainage operation line, the concrete lining operation line, the maintenance operation line and the groove operation line to simulate the distribution law of oxygen concentration in the tunnel construction process. The Sejila Mountain Tunnel has an elevation of more than 3000 and a length of more than 2 km. In principle, it is supported by large-scale mechanization[3]. Estimated diesel consumption under different construction procedures of the Sejila Mountain Tunnel is shown in Table 1.

Table 1. Formatting sections, subsections, and subsubsections.

| Construction process        | Equipment                                      | Engine power (kW) | Diesel fuel consumption (kg/h) |
|-----------------------------|------------------------------------------------|-------------------|-------------------------------|
| Excavate the operation line | Three-arm full hydraulic drilling rig          | 125               | 41.68                         |
| Shipping line               | Loaders, ballast trucks                        | 600               | 200.07                        |
| Support line                | "Drilling, injection, anchor" integration of special anchor trolley | 252               | 84.03                         |
| Check the bottom laying line| Excavators, dump trucks, concrete mixing truck| 595               | 165.05                        |
| Drainage line               | Waterproof board automatic laying trolley      | 55                | 18.34                         |
| Concrete lining operation line| Intelligent formwork trolley and concrete mixing conveyer | 245               | 81.7                          |
| Maintenance line            | Maintenance trolley                            | 20                | 6.669                         |
| Groove operation line       | Groove car                                     | 20                | 6.669                         |

3 Numerical simulation analysis

3.1 Calculation model and calculation parameters

The oxygen content in the tunnel was simulated by using CFD Fluent software. In order to study the oxygen mass concentration distribution at the tunnel palm face, the model size adopts the horseshoe section of the actual size of the tunnel. The three-dimensional geometric model is established by ANSYS Workbench, and the model is meshed by an unstructured grid with grid adaptive ability as shown in Figure 1. The boundary conditions are set in Table 2.

The oxygen consumption of an internal combustion engine in high altitude tunnel construction can be calculated by the following formula:

\[ V_{O_2} = 24 \times \frac{m_f}{\rho_{O_2} M_f} \]  

Where \( V_{O_2} \) represents volume of oxygen consumption (m³/h); \( m_f \) represents fuel consumption (kg/h); \( M_f \) represents equivalent molar mass of fuel (kg/mol); \( \rho_{O_2} \) represents density of oxygen (kg/m³), conversion from standard atmospheric pressure density; 24 represents burning 1 mol of diesel fuel requires approximately burning 24 mol of oxygen; 32 represents molar mass of oxygen.

The oxygen density of the Sejila Mountain Tunnel is 0.85256 kg/m³, and its oxygen consumption and gas production are shown in Table 3.

Table 3. Gas generation and emission during tunnel construction.

| Constructon process | Oxygen consumption (m³ /s) | Carbon dioxide emission (m³ /s) | Water vapor emission (m³ /s) |
|---------------------|-----------------------------|-------------------------------|-----------------------------|
3.2 Calculation analysis

In the post-processing of this paper, CFD-POST software is mainly used to process various cloud images. The Origin software is used to convert the output text data into a concise graph to facilitate the analysis and processing of its data results. When the operating power at the tunnel face is 600kW, 650kW, 700kW, 725kW, 750kW, and 800kW, the simulation results are as follows.

Under unsteady conditions, the variation of oxygen mass concentration with the hole body 100 meters after 1 hour of construction under different construction power is shown in Fig. 2, 3.

![Fig. 2. Variation of oxygen mass concentration at 100 meters of tunnel body after 1-hour construction under different construction power.](image)

It can be seen from Fig. 4 and 5 that the maximum oxygen concentration is 0.23 at the tunnel entrance. With the excavation of the tunnel face, the oxygen mass concentration shows a downward trend. Due to the interval between the working area of the tunnel face and the working area along the tunnel, it increases and then decreases at 15 m from the tunnel face. With the increase of mechanical power at the tunnel face, the oxygen mass concentration decreases at 70 m away from the tunnel face and decreases everywhere in the tunnel.

In the unsteady state, the variation of oxygen mass concentration with the whole body at 100 m after two hours of construction under different construction power on the working face is shown in Fig. 5 and Fig. 6. From the cloud images and curves, the distance between the tunnel body and the tunnel face is less than 15 % from 73 meters in 2 hours, and it tends to be 0.

![Fig. 4. Variation of oxygen mass concentration at 100 meters of tunnel body after 2-hour construction under different construction power.](image)

![Fig. 5. Variation of oxygen mass concentration at 100 meters of tunnel body after 2-hour construction under different construction power.](image)

Figs 6 and 7 are the variation of oxygen mass concentration at 5 meters from the tunnel face after 1 hour and 2 hours of construction under different tunnel face construction power. Because the pollution source is located at the bottom of the tunnel, the oxygen mass concentration of the tunnel section shows a trend of high in the middle of the top and middle-low sides, and the section’s oxygen concentration decreases with the power increases.
By studying the change of oxygen mass concentration near the tunnel face, it is concluded that the oxygen mass concentration changes with the tunnel body at the construction power of 725 kW for 20 min, 40 min, 60 min, 80 min, 100 min, and 20 min, as shown in figure 8.

As can be seen from Fig. 8, with the increase of time, after 40 min, the oxygen mass concentration began to decrease rapidly at about 20 m from the palm surface, and after 60 min, it began to decrease linearly at 40 m. After 80 min, it began to decrease linearly to 26 m; after 100 min, it initially decreased to 21 m; after 120 minutes, 30 meters down rapidly.

Fig. 9 shows the variation of oxygen mass concentration at different excavation lengths of the tunnel face for one hour. It can be seen from the figure that with the increase in excavation length, the oxygen content along with the tunnel decreases, and the overall variation trend of the tunnel is the same. The oxygen mass concentration first tends to be flat, and the oxygen mass concentration begins to decrease significantly at about 72 m near the tunnel face and fluctuates at 50 m near the tunnel face.

4 Conclusion and foresight

Based on the relevant theories and research, this paper uses Fluent software to analyze the main factors affecting the oxygen mass concentration in the tunnel construction process by numerical simulation method and summarizes the changes in the oxygen concentration field with different influencing factors without environmental control.

The oxygen consumption and emission of the internal combustion engine and the length of tunnel excavation are important factors affecting the oxygen concentration of the tunnel face and along the tunnel. The variation law of oxygen mass concentration in the tunnel under different power conditions is basically the same. The lower the oxygen concentration is closer to the tunnel face, the higher the oxygen concentration is closer to the tunnel outlet. The greater the power of the internal combustion engine, the faster the oxygen concentration decreases. With the increase in the construction time, the oxygen mass concentration in the tunnel decreases and is far lower than the standard requirements. As the excavation length increases, the oxygen concentration everywhere in the tunnel decreases, but the overall change trend is the same.

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