Numerical Analysis of Free Dust Diffusion Law in Large Section Construction Tunnel

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Abstract. The Youzhushan tunnel (large section double-track railway tunnel) is used as the research background, the concentration distribution of the free dust diffusion trajectory after blasting in the working face was numerically simulated by using the finite element computational fluid dynamics software Ansys-CFD. The simulation results were compared with the field measured data, and the results are basically consistent. The results show that the lining trolley is the main equipment to hinder the dust diffusion, the free dust on both sides of the lining trolley has a clear boundary, and the high concentration of free dust has not been well diffused. A vortex area appears near the entrance of the adit level, which forces the free dust from the tunnel to do vortex circulation. The dust removal rate of parallel guide is about 66.5% after 800 seconds of ventilation and about 76.6% after 2400 seconds of ventilation. The drainage effect of parallel guide is more obvious when the dust concentration in the tunnel is lower.

1. Introduction
In the process of tunnel excavation and mining operations, a large amount of dust will be generated during drilling, blasting, shotcreting and other processes. Among them the dust concentration at the worker's work site can reach as high as 2000mg/m³. Operation in this environment the workers are bound to be inhalation of large amounts of dust, especially respiratory dust can cause pneumoconiosis. Data released to the public by National Health and Family Planning Commission from 2019 to 2020: A total of 183875 occupational disease cases were counted. Among them, 154853 cases of pneumoconiosis, accounting for 84.22% of the incidence of occupational diseases. Generally, it is difficult to solve the problem of dust pollution by using forced ventilation in tunnels with a length of more than 3km. There are many mountainous areas and complex terrain in China, a new railway network in the western region accounts for more than 60% of the tunnels, and tunnels over 3km are everywhere. Therefore, studying the movement trajectory, migration law and concentration distribution of dust under the tunnel ventilation is of great theoretical and guiding significance for improving the construction working environment, protecting the physical and mental health of workers, and saving construction time.

2. Flow Field Calculation Model
In this paper, the discrete phase model in Euler-Lagrange equation is used to calculate the movement law and concentration distribution of dust particles. The discrete phase mathematical model is based on the continuity equation and the momentum equation, using the Realizable k-ε flow model, the
SIMPLE algorithm is used to solve the Navier-Stokes equation. Due to the limitation of space, the mathematical models are not repeated here.

2.1. The Establishment of Geometric Model
According to the actual situation of the Youzhushan tunnel a 3D model was set with length of 65m, height of 12m, and high of 9m. The diameter of the air pipe is 1.5m. The location of the air pipe is on the sidewall of the tunnel. The distance between the trolley I and the working face is 18m. The centreline of the parallel guide is 45m away from the working face, as shown in Figure 1.

![Figure 1. Dimension of tunnel 3D model space](image1)

![Figure 2. Tunnel model mesh](image2)

2.2. Computational Domains and Boundary Conditions
In order to reduce the amount of calculation data and maintain the accuracy of the calculation, the tunnel is divided into unstructured mesh in 3D model. The mesh is not densified separately in this research in order to study the diffusion law of dust in the whole tunnel. A total of \(9.12 \times 10^5\) meshes, as shown in Figure 2.
Generally, about 98% of the dust particles discharged into the atmosphere after working face blasting are extremely fine quartz particles and debris. Its main component is SiO\(_2\), and its density is 2200kg/m\(^3\). The remaining components mainly include soil rock dust, sandstone dust, Gray shale dust, carbonaceous shale, granite dust, etc. so this article mainly discusses free SiO\(_2\) dust. The discharge of blasting pollutants belongs to instantaneous intermittent discharge. Taking tunnel Youzhushan as an example, the average total dust flow rate of dry operation method is about \(9.42 \times 10^{-4}\)kg/s, (free SiO\(_2\) dust is taken as 98%, and the dust flow rate is about \(8.48 \times 10^{-4}\)kg/s), and the average duration is 0.2s. The parameter settings in Ansys-CFD are shown in Table 1.

**Table. 1** Setting of the boundary conditions and the solver in flow field

| Model     | Define                        | Boundary name       | Define     | Magnitude |
|-----------|-------------------------------|---------------------|------------|-----------|
| Solver    | Pressure-based/Absolute       | Air pipe            | Velocity-inlet | 3.62m/s   |
| Time      | Stead/Transient               |                      | Hyd-diameter | 1.5m      |
| Viscous   | k-epsilon (2 eqn)            |                      | Tur-intensity | 4.27%     |
| Discrete Phase | On                       | DPM condition       | trap       | /         |

3. Numerical Simulation Results and Analysis

3.1. Analysis of Dust Evacuation Trajectory
The unsteady solver (Transient) is used to obtain the running trajectory of the free dust in the tunnel and the residence time distribution in the space position when the ventilators are turned on after the
face blasting, as shown in Figure 3.

It can be seen from Figure 3:
- After the free dust is generated from the working face, it runs to the tunnel under the pressure of the ventilators, and a circulating vortex flow is generated between the lining trolley and the working face. This situation shows that the lining trolley has a certain hindrance effect on the dust diffusion, the residence time of dust at the working face is short, and the residence time at the lining trolley is longer.
- After ventilating for a period of time, a large amount of free dust crossed the lining trolley I and continued to move into the tunnel. Obstructed by the lining trolley II the dust gathered between the two trolleys and stayed at this position for a longer time. It shows that a small amount of free dust stays in this area for the longest time and has not been well evacuated. It can be seen that there is a clear demarcation of dust concentration on both sides of the lining trolley, this is due to the obstruction of air flow by lining trolley.

3.2. Analysis of Dust Concentration Distribution Law
Based on the height of the breathing zone of the general construction personnel is about 1.5m, in order to study the impact of dust on the construction personnel, two monitoring lines of free dust with a height of 1.5m are set on the central axis of the tunnel ($L_t$) and the parallel guide ($L_p$).

Figure 4. The concentration distribution curve of free dust in space position at different time under the condition of ventilation.
Where \( L_t = \{ p_0(x_0=6, y_0=1.5, z_0=0), p_1(x_1=6, y_1=1.5, z_1=65) \}, L_p = \{ p_0(x_0=19.88, y_0=1.5, z_0=44), p_1(x_1=19.88, y_1=1.5, z_1=65) \} \). After the ventilators run for 200s, 500s, 600s and 800s, the concentration values of free dust are collected and the results are shown in the figure 4. It can be seen that:

- After purifying for 200s, the free dust with high concentration is gathered in front of the lining trolley I \((Z_1=[18, 23])\), there was a maximum concentration point at \(Z=18.86m \left(8.828 \times 10^{-4} \text{kg/m}^3 \approx 883 \text{mg/m}^3\right)\).

- After 500s of air supply, the free dust concentration in the tunnel decreased, and the dust concentration in front of the lining trolley I was released, but a large amount of dust still gathered in this area, and the maximum concentration appeared at \(Z=16.12m \left(189 \text{mg/m}^3\right)\). Under the influence of air pressure, the dust continues to move towards the tunnel entrance.

- After 600s of air supply, high-concentration dust gathered again in front of the lining trolley II \((Z_2=[36, 41])\), the concentration extreme point \(\left(4.533 \times 10^{-4} \text{kg/m}^3 \approx 453 \text{mg/m}^3\right)\) appeared at \(Z=34.13m\), the reason is still caused by the obstruction of the lining trolley.

- After 800s of air supply, the free dust in the tunnel starts to move into the adit level. There is a large drop in the dust concentration in the tunnel near the adit level \((Z=45)\), which indicates that the dust in the tunnel starts to move toward the adit level under the guidance of the ventilation. The free dust concentration has a maximum concentration point \(\left(2.355 \times 10^{-5} \text{kg/m}^3 \approx 23.5 \text{mg/m}^3\right)\) at \(Z=58.44m\) in the tunnel behind the adit level, and the maximum concentration appears at \(Z=55.36m\) in the parallel guide \(\left(4.676 \times 10^{-5} \text{kg/m}^3 \approx 46.8 \text{mg/m}^3\right)\). The free dust concentration in the parallel guide is about 2 times higher than that in the tunnel. It shows that most of the dust has been evacuated from the parallel guide, and the dust removal rate of the parallel guide is about 66.5% after 800s of air supply.

4. Data Comparison and Analysis

According to GBZ/T192.1-2007 Workplace Air Dust Determination Part 1: Total Dust Concentration and the sampling arrangement and method in related literature, a total of 10 monitoring points were set up at the height of the breathing zone in the tunnel and the parallel guide. The free dust concentration in the tunnel was measured after the blasting of the working face for 800s. The location of the field monitoring points is shown in Figure 5.

**Figure 5.** Location of field monitoring points of tunnel Youzhushan

A microcomputer laser dust analyzer (LD-3C) is used to measure the concentration of free dust in tunnel Youzhushan. At least 3 data measurements are taken at each measuring point and the average value is taken as the final value, and the result is compared with the numerical simulation result. The comparison between measured data and simulated data is shown in Table 2.

**Table 2.** The comparison between measured data and simulated data

| monitoring points | a  | b  | c  | d  | e  | f  | g  | h  | i  | j  |
|-------------------|----|----|----|----|----|----|----|----|----|----|
| Measured Value    | 56.011 | 53.289 | 71.899 | 26.031 | 60.554 | 18.025 | 26.112 |
| Simulated Value   | 51.756 | 49.217 | 73.108 | 29.005 | 63.490 | 21.227 | 29.604 |

As can be seen from Table 2: The simulation results are basically consistent with the actual measurement on site, and the distribution law is basically similar. It verifies the accuracy of the
simulation results. Numerical simulation can be used to calculate the dust diffusion trajectory and concentration distribution in the construction tunnel under different boundary conditions (addition of fans, relay fans, etc.). The parameters of the ventilation and dust removal system can be optimized before the tunnel construction which greatly saves manpower, material resources and financial resources. It can also predict the diffusion trajectory and concentration distribution of other harmful substances (gas) during the construction process.

5. Conclusion
Through the simulation study and field measurement of dust concentration distribution in different periods of time under ventilation operation in tunnel Youzhushan, the following conclusions are drawn:

- Lining trolley is the main equipment to hinder the spread of dust. Therefore, setting a relay fan inside the lining trolley can increase the diffusion speed of dust and reduce the purification time.
- Under the combined action of the forced ventilator and the relay ventilator, the dust removal rate is about 66.5% in the parallel guide after 800s of ventilation. It shows that the drainage effort of parallel guide is more obvious when the free dust concentration in the tunnel is low.
- The Ansys-CFD discrete term unsteady model (DPM) is used to analyze the dust migration in construction tunnels, which can objectively reflect the migration law and diffusion of free dust in different time periods. It is suitable for analyzing the characteristics of dust migration.

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