Study on Air Quality Monitoring and Numerical Simulation Optimization in Shenyang Metro Station

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Abstract: Air quality monitoring was carried out at the three stations A, B and C of Line 1, Line 2 and Line 9 of Shenyang Subway station. CO₂, formaldehyde, TVOC and PM2.5 were selected as pollutants. The results indicate that because the platform floor is far from the ground and there is almost no natural ventilation, the concentration of pollutants is higher than that of the station hall floor. The formaldehyde concentration of the newly built site A exceeded the standard by 37.1%. CFD was used for numerical simulation, and the section with human respiratory height Z=1.5m was selected as a typical section. The cloud map of temperature, velocity and concentration distribution of typical pollutants were analyzed to find out the areas where the concentration of pollutants exceeded the standard and analyze the reasons. The layout of tuyere which can improve the air quality in subway station is proposed, and the simulation and optimization research is carried out.

1. Introduction

With the emergence of ground traffic congestion, subway has become an important way of transportation in modern cities with its advantages of high speed, high efficiency and comfort.

The research¹¹ shows that the indoor thermal environment with good air distribution is very important. Because the subway system is a relatively closed environment, the air quality, can only be adjusted through the air conditioning system, which is very unfavorable for the dilution of pollutants in the air²². When the human body is in a crowded and airless environment, it is easy to produce bad emotions, which affect people's physical and mental health³³. Therefore, many experts and scholars begin to study the air pollution in subway stations. Adams has⁴⁴ found that PM2.5 concentration in London underground station had seasonal difference. Zhang Lin⁵⁵ found that radon concentrations in subway stations are different in different seasons and at different times of the day. Nowadays, CFD is naturally applied to the three-dimensional simulation of subway environmental control. Yuan Feng dong⁶⁶ used Airpak to optimize the platform ventilation scheme through the simulation results of temperature field and velocity field. In this paper, while the air quality of Shenyang subway is monitored, CFD is used to carry out simulation optimization research, in order to put forward the arrangement form of tuyere which can improve air quality in the subway.

2. Monitoring methods and results

2.1. Monitoring methods

A, B and C stations of Shenyang Metro are selected as representative stations. Each platform and station hall are set up with 4 sampling points. Each pollutant parameter index was monitored for three
times, and the final results were averaged for three times. July 2019 is selected as the typical summer month, and December 2019 as the typical winter month. Three working days are continuously monitored every month. Three time intervals were monitored every day, morning peak 7:00—9:00, Off-peak hours11:00—13:00, Evening peak17:00—19:00.

2.2. Monitoring results and analysis

![Figure 1 CO2 concentration of station hall and platform](image1)

![Figure 2 formaldehyde concentration of station hall and platform](image2)

![Figure 3 TVOC concentration of station hall and platform](image3)

![Figure 4 PM2.5 concentration of station hall and platform](image4)

Figure 1-figure 4 shows that the average concentration levels of CO2, TVOC and PM2.5 in the air of subway station are far lower than the reference standard limit, while the formaldehyde concentration level of station A almost reaches the upper limit. Compared with the air quality of each station, the CO2 concentration of station C is higher than that of station B and A. This is because the passenger flow of station C is the largest. The TVOC and formaldehyde concentration of station A were significantly higher than those of station B and C, and the formaldehyde exceeding standard rate reached 37.1%. This is due to the short construction time of site A, decoration materials and thermal insulation materials are relatively new. The concentrations of TVOC, CO2 and formaldehyde in the platform area of the same station were slightly higher than those in the station hall area, which were 43.6%, 6.98% and 37.9% higher respectively. The main reason is that there are entrances and exits to the outside world in the station hall. In addition, the platform as the waiting area for passengers, the crowd density is higher than that of the upper station hall floor.

3. Simulation model

3.1. physical model

According to the design drawing of a subway in Shenyang, the model is built as figure 5, and the scale between the model size and the actual size is 1:1. The size of the model is 58m (length) × 12m (width) × 3.3m (height).
3.2. Mathematical model

The indoor air flow is dominated by physical conservation. These conservation equations are as follows:

Mass conservation law
\[
\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0 \tag{1}
\]

Momentum conservation law
\[
\frac{\partial (\rho u)}{\partial t} + \frac{\partial (\rho u^2)}{\partial x} = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{x}}{\partial x} + \rho g_x + F_x \tag{2}
\]

Conservation of energy law
\[
\frac{\partial (\rho T)}{\partial t} + \text{div}(\rho \overrightarrow{U} T) = \text{div}\left(\frac{K}{C_p} \text{grad} T\right) + S_t \tag{3}
\]

Species mass-conservation law
\[
\frac{\partial (\rho C_i)}{\partial t} + \text{div}(\rho \overrightarrow{U} C_i) = \text{div}(D_i \text{grad}(\rho C_i)) + S_i \tag{4}
\]

3.3. Boundary condition

Table 1. Boundary conditions

| Boundary name         | Type               | Set project       | Unit     | Numerical value |
|-----------------------|--------------------|-------------------|----------|-----------------|
| Air inlet             | Speed inlet        | Velocity          | m/s      | 2.1             |
|                       |                    | Temperature       | K        | 291             |
| Escalator             | Wall               | Heat flux density | W/m²     | 100             |
| Floor                 | Mass flow inlet    | Emission rate     | Kg/s     | 1.2e-08         |
| Column                | Mass flow inlet    | Emission rate     | Kg/s     | 1.2e-08         |
| Ceiling               | Wall               | Heat flux density | W/m²     | 20              |
| Shielding door        | Wall               | Heat flux density | W/m²     | 26              |

4. Simulation results and simulation optimization

4.1. Simulation results

Taking the standing human breathing height \( z = 1.5 \text{m} \) section as a typical section. The velocity field, temperature field and formaldehyde concentration field were comprehensively analyzed.
Figure 6. Velocity field distribution

Figure 7. Temperature field distribution

Figure 8. Formaldehyde concentration field distribution

It can be seen from fig.6-8 that the average speed is about 0.2 m/s, and the air flow forms around when encountering obstacles such as columns and escalators, which leads to the increase of speed, but also keeps below 0.3 m/s. The average temperature is about 297 K, but the temperature in the right half of the area on the side of the return air is higher, reaching 300 K. The formaldehyde concentration at the air return side is significantly higher than that at the air supply side. This is because formaldehyde flows with the air, and the density of formaldehyde is higher than that of air, so it slowly sinks in the process of flow, and finally deposits at the air return side, which makes the formaldehyde concentration increase. The formaldehyde concentration is lower in the place with higher wind speed.

4.2. Simulation optimization

According to the results, the formaldehyde concentration has a great relationship with the position of air supply and return outlets. Therefore, this paper puts forward another way of air outlet layout, that is, air supply and return outlets are arranged on both sides. And the simulation is carried out.

Figure 9. Velocity field distribution
It can be seen from fig.9-11 that the average speed and temperature still meets the design requirements. Moreover, the area of vortex zone is obviously reduced, and the temperature distribution on both sides is more uniform. Compared with figure 8 the average concentration of formaldehyde decreased by 10.6%. And the concentration difference between the two sides is not obvious, there is no excess phenomenon caused by the accumulation of concentration on one side. This shows that the method of setting air outlet on both sides can effectively reduce the formaldehyde concentration.

5. Conclusion
The formaldehyde concentration of the newly built site A exceeded the standard by 37.1%, and the concentrations of various pollutants in other sites were in line with the limits of the health standards.

The concentrations of TVOC, CO₂ and formaldehyde in the platform area were 43.6%, 6.98% and 37.9% higher than those in the station hall area, respectively.

The air supply mode with air return outlets on both sides is more conducive to the emission of formaldehyde in the subway station, and the formaldehyde concentration decreases by 10.6%. In addition the temperature distribution is more uniform, the overall air mobility is better, and the comfort is better.

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