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The Characteristics of Pollutant Diffusion and the Crossflow in Adjacent Tunnel Portals

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Abstract: With the development of infrastructure construction, tunnel construction is becoming more and more. However, the pollution diffusion from adjacent upstream tunnels can cause secondary pollution to downstream openings. The paper used FLUENT to simulate the characteristics of pollutant diffusion. Two forms of adjacent tunnels, single-hole tunnel and double-hole tunnel, were used as the research objects. Also simulate the interporosity flow issue, it is concluded that when the tunnel wind speed is equal, the interporosity flow has nothing to do with the wind speed, but has to do with the distance between upstream and downstream spacing.

Keywords: Adjacent Tunnels, Pollutant Diffusion, Crossflow, Tunnel Ventilation Speed

1. Introduction

The existing ventilation design of tunnels is aimed at individual tunnels, which is not suitable for adjacent tunnels. Tunnels with closer upstream and downstream spacing are called adjacent tunnels, It is also divided into the single-hole adjacent tunnel and the double-hole adjacent tunnel. Downstream hole will inhale pollutants discharged from upstream tunnel hole and cause interporosity flow, the original design could only ensure the ventilation requirements of the upstream tunnel, however, there was no guarantee that the concentration of pollutants in the downstream flow tunnel are under control.

At home and abroad the problem of pollutant diffusion in the hole has been studied by measuring on the spot and experimenting with models [1-2]. In addition, The Chinese Academy of Sciences adopted the method of numerical simulation, The problem of mixed wind in Unidirectional double-hole tunnel was discussed, and the effective measures of reducing the mixed wind are put forward [3], Southwest Jiao Tong University simulated diffusion interporosity flow rule under various operating conditions, experiments are carried out and the rules are verified[4] . Chongqing Jiao Tong University, on the other hand, has made studies on the transverse and longitudinal interporosity flow at the tunnel [5].

None of the above work involves adjacent double-hole tunnels, and the contents of the research are mostly aimed at a particular tunnel form, there were not making analysis for the characteristics of pollutant diffusion. Based on the Fluent fluid calculation software and the relative concentration of CO as the evaluation parameter, this paper discusses the influence of wind speed variation on the law of crossflow, and comparing the characteristics of pollutant diffusion between two kind of adjacent tunnels and single tunnel by the aspect of wall-attached-jet [6-7].

2. Establishment and Solution of Models

2.1. Mathematical Model

The flow can be regarded as a steady flow of incompressible fluid. Based on the component transport model, the $k-\varepsilon$ equation of incompressible constant flow and the simple algorithm are adopted. The turbulent governing equations such as mass conservation equation, momentum conservation equation, energy conservation equation and component transport conservation equation are followed [8].

(1) mass conservation equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

(2) momentum conservation equation

$$\iiint_{V(t)}\rho\frac{\mathrm{d}u}{\mathrm{d}t}=\iiint_{V(t)}\rho F dv+\iint_{s(t)} n\sigma dS \quad (2)$$

(3) energy equation

$$\frac{\partial(\rho T)}{\partial t}+div(\rho\mu T)=div\left(\frac{k}{c_p}gradT\right)+S_T \quad (3)$$

(4) conservation equation of component transport

$$\frac{\partial(\rho C_a)}{\partial t}+div(\rho\mu C_a)=div\big(D_a grad(\rho C_a)\big)+S_a \quad (4)$$

2.2. Physical Model

As shown in figure 1, Suppose the section at the hole of the tunnel is a wall surface, the topography outside the cave is horizontal, the section of the tunnel is simplified to a rectangle with a size of 9m x 5m.Each length of the tunnel is 10 times the diameter of the tunnel, which is about 70m. The outer atmospheric area of the tunnel is 8 times the equivalent diameter length, which is about 50m. If, in the direction of the jet flow, the length of the outer area of a single-hole tunnel takes 30 times the equivalent diameter, which is about 200m.

Boundary condition. Tunnel walls, mountains and floors are all implied as wall boundary, the inlet and outlet of the air flow adopt the velocity boundary, the outer atmosphere is a free boundary, without thinking about the impact of the traffic, there are no other heat sources and ambient winds in the calculation domain.

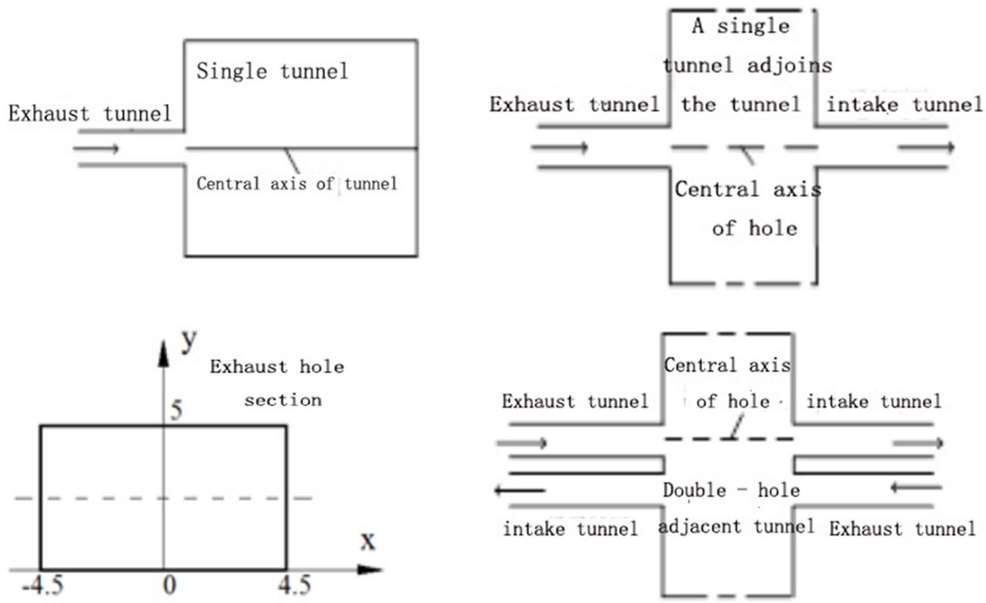

Figure 1. *The schematic diagrams f three tunnels.*

3. The Characteristics of Pollutant Diffusion

The distance between adjacent tunnels is 34m, and the ventilation speed of the tunnel is 5m/s. The characteristics of pollutant diffusion of a single-hole tunnel are typical wall-attached-jet. The characteristics of pollutant diffusion in adjacent tunnels can be compared from two aspects: the central axis and cross section of the jet direction. The height of the central axis is 2.5m, which is half of the height of the hole, the cross section is located at the midpoint and parallel to the hole.

3.1. Movement Characteristics of Pollutant Diffusion at the Central Axis of the Hole

According to the motion characteristics of the attached jet, along the direction of the jet, the axial velocity remains unchanged in the initial section until the transition section, then the jet enters the main section, and the axial velocity decreases continuously. As shown in FIGURE 2, within the range of 34m, the fluid channeling of single-hole is still at the initial stage, the speed is basically unchanged, there is the same situation with the single-hole adjacent tunnel, However, the wind speed of the single-hole adjacent tunnel near 30m will increase due to the influence of the suction air from the downstream hole. There are two air outlets and two air inlets in the double-hole adjacent tunnel. After pollutant diffusion is discharged, it will be affected by the air inlet of the adjacent tunnel, o that it will deviate from the axis to the adjacent tunnel, the lateral fluctuation will increase, and the velocity component on the axis will continue to decline. But at the midpoint, the encounter of two strands of airflow will lead to a serious loss of momentum and a sharp drop in speed to the lowest point. After that, the airflow is affected by the inflow from the downstream hole, and the velocity will slowly rise to the inlet velocity of the tunnel at the downstream hole.

The change in velocity naturally brings changes in CO concentration (Table 1). The diffusion of single hole is concentrated, and the CO concentration on the central axis can maintain the initial high concentration. When the tunnel is adjacent to the double tunnel, the initial concentration of exhaust gas can be maintained on the central axis of the vent hole before the two exhaust gas flows meet. But after the encounter, due to the deviation of the diffusion direction, the disorder of transverse pulsation brings more ambient air, and then the concentration of CO decreases. When the airflow reaches the vicinity of the downstream holes, it will mix with the exhaust gas discharged from the other exhaust holes, and then the concentration will only slightly increase.

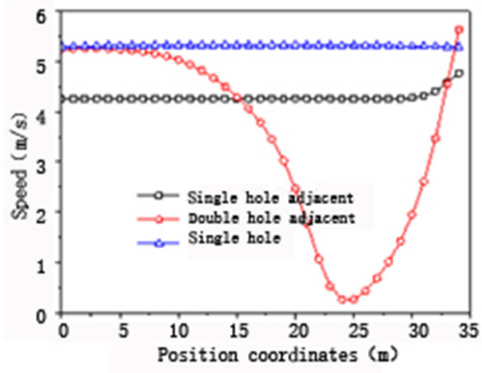

Figure 2. *Speed of the central axis of the tunnel.*

Table 1. *CO concentration of the central axis of the tunnel.*

The distance of the tunnel portals /m	Single-hole	Single-hole adjacent tunnel		Double-hole adjacent tunnel	
	Relative concentration of CO (%)	Relative concentration of CO (%)	Deviation rate (%)	Relative concentration of CO (%)	Deviation rate (%)
1	100.00	100.00	0.00	100.00	0.00
5	100.00	100.00	0.00	99.95	0.05
9	100.00	100.00	0.00	99.89	0.11
13	100.00	100.00	0.00	99.45	0.55
17	99.99	99.99	0.00	99.23	0.76
21	99.98	99.97	0.01	94.93	5.05
25	99.92	99.90	0.01	61.94	38.01
29	99.72	99.66	0.06	49.55	50.31
33	99.19	97.44	1.76	56.25	43.29

3.2. Motion Characteristics in Cross Section

Figure 3 shows the change of velocity in the cross section at the midpoint of 17m, and the velocity in the middle section of the single tunnel remains basically unchanged, which is the core velocity of the jet starting section. The same is true for the single tunnel adjacent to the tunnel. However, due to the joint action of the upstream and downstream holes, the movement at the midpoint of a single tunnel adjacent to the tunnel is slightly complicated and the speed is smaller. Because of the transverse pulsation on the axis, the velocity value of the double tunnel adjacent to the tunnel is smaller than that of the single tunnel, and the peak value is also biased toward the outer side which is less affected. This also causes the deviation of CO concentration. Compared with the single hole jet, the jet adjacent to the hole in the single hole is only slightly different on both sides, while the jet adjacent to the double hole changes greatly, and the deviation rate of CO relative concentration on one side even reaches more than 40 %.

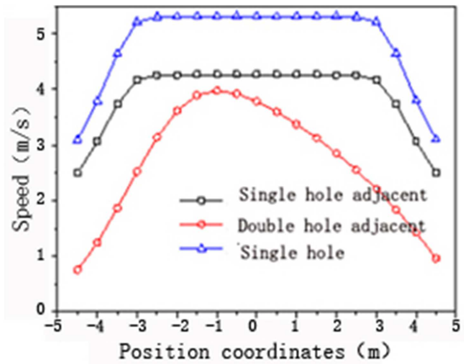

Figure 3. *Speed of the cross-section at the midpoint.*

Table 2. *CO concentration of the cross-section at the midpoint.*

Coordinate position /m	Single-hole	Single-hole adjacent tunnel		Double-hole adjacent tunnel	
	Relative concentration of CO (%)	Relative concentration of CO (%)	Deviation rate (%)	Relative concentration of CO (%)	Deviation rate (%)
-4	74.16	76.30	2.88	44.07	40.57
-3	98.15	98.17	0.02	66.44	32.31
-2	99.99	99.98	0.00	86.06	13.93
-1	99.99	99.99	0.00	96.40	3.60
0	99.99	99.99	0.00	99.23	0.76
1	99.99	99.99	0.00	99.77	0.22
2	99.99	99.98	0.00	99.73	0.26
3	98.19	98.18	0.01	99.44	1.27
4	74.31	76.33	2.72	99.02	33.25

4. Analysis of the Influencing Factors of Hole Crossflow

4.1. Influence of Distance Between Upstream and Downstream

When the wind speed of the tunnel is 5m / s, the degree of cross-flow between adjacent tunnels of single-hole and adjacent tunnels of double-hole decreases with the increase of the distance between upstream and downstream. The curve fitting is listed in Table 3. From the formula, it can be seen more clearly that compared with the linear relationship that the cross flow of a single hole continuous tunnel decreases uniformly with the increase of the spacing, the cross flow of a double hole adjacent tunnel is closer to the power function form than that of a single hole continuous tunnel, and decreases gradually with the increase of the spacing.

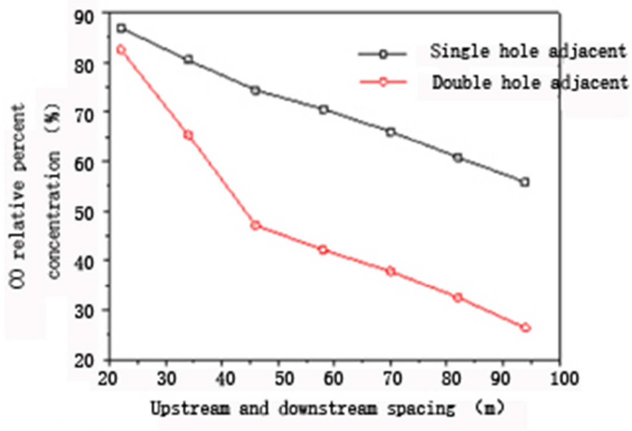

Figure 4. *The relationship between CO concentration and spacing.*

Table 3. *The fitting formulas between CO concentration and tunel spacing.*

	Fitting formula	Fitting degree R^2
Single-hole continuous tunnel	$\varphi = -0.4196 \cdot S + 95.023$	0.9954
Double - hole continuous tunnel	$\varphi = 799.55 \cdot S^{-0.712}$	0.9831

4.2. Influence of Tunnel Wind Speed

Wind speed is within the range of tunnel design ventilation wind speed (≤ 10m / s). As can be clearly seen from Figure 5, the relative concentration of co in adjacent tunnels is basically unchanged regardless of the value of ventilation speed in the tunnel, while the actual data calculated that the change range is only within 5 %. So it can be judged that the cross flow at the entrance of adjacent tunnels is basically independent of the ventilation speed of the tunnel, regardless of the single hole and double holes, under the premise of equal air intake and exhaust speed.

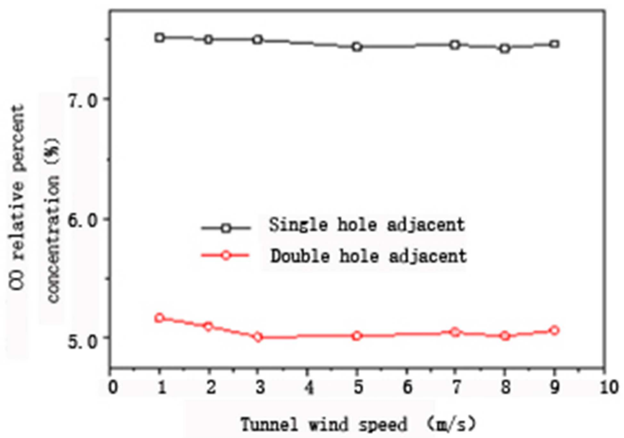

Figure 5. *The relationship between interporosity flow and ventilation speed.*

5. Conclusions

(1) The exhaust gas diffusion at the tunnel holes is basically in line with the characteristics of the attached jet movement, but the adjacent tunnel will cause a certain deviation due to the mutual influence between the holes. The deviation of CO relative concentration in the cross-section of the tunnel adjacent to a single tunnel at the central axis and midpoint of the tunnel hole is about 2 % and 3 % respectively, while the deviation rate of CO relative concentration in the tunnel adjacent to a double tunnel is about 50 % and 40 % respectively due to the complicated form of the tunnel hole.

(2) Under the condition of equal tunnel ventilation speed, whether the adjacent tunnel is single-hole or double-hole, its entrance channeling has nothing to do with the magnitude of tunnel wind speed, but it is related to the distance between tunnel entrances, and decreases with the increase of the distance.

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