Effect of Hedgerows on CO Diffusion from Vehicle Exhaust Emissions in Street Canyons

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Abstract. This paper studies the influence of hedgerow green belt on the flow field of street canyon and the CO diffusion of vehicle emission in street canyon. The commercial CFD package and post-processing software were used for numerical simulation and analysis. The green belt was established as a porous medium model. The steady-state standard k-turbulence model combined with the component transport equation was used to simulate the CO diffusion process of vehicle exhaust in the street canyon with hedgerows on both sides of the road. The simulation results were compared with the wind tunnel test to verify the accuracy of the results. It is found that the flow field in the street canyon changes after the slope transformation of the hedgerow green belt on both sides of the street. Compared with several working conditions, it is found that the overall CO concentration in the street canyon after transformation is lower and the CO diffusion situation is better than that before transformation, no matter in the case of low or high wind speed.

Keywords: Street canyon · Hedgerow · Pollutant dispersion · Numerical simulation

1 Introduction

With the rapid development of cities, the number of motor vehicles becomes more and more, and the pollution problem caused by motor vehicle exhaust is more serious. Especially in urban streets, due to the special structure of the street canyon itself, the diffusion of motor vehicle exhaust is hindered, and the exhaust pollution in the street valley is aggravated [1], which seriously endangers the health of surrounding residents and pedestrians. The layout of green belts in street valleys can not only play an aesthetic role, but also dust removal and purify the air. However, relevant studies show that the layout of green belts in street valleys can affect the flow field and pollutant diffusion, reduce the ventilation efficiency in the street valleys, and make the overall concentration of pollutants in the street valleys higher [2]. Therefore, how to arrange green belts to

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improve ventilation efficiency and pollutant diffusion in the street valley has practical and important research significance. This paper focuses on the impact of the green belts (hedgerows) on the side of the street canyon road with the aspect ratio of 1:1 on the CO diffusion of automobile emissions.

2 Method

2.1 Numerical Model

The establishment of the street valley model is shown in Fig. 1. Hedgerows are arranged on both sides of the driveway. The green isolation bandwidth is 0.8 m, the height is 1 m, the sidewalk width is 3 m, the overall street width is 15 m, the building height on both sides is 15 m, and the heighter-width ratio of the street canyon is 1:1. The pollution source is set as the CO entrance of the line source, and the exit is located in the center of the driveway to simulate automobile exhaust emissions.

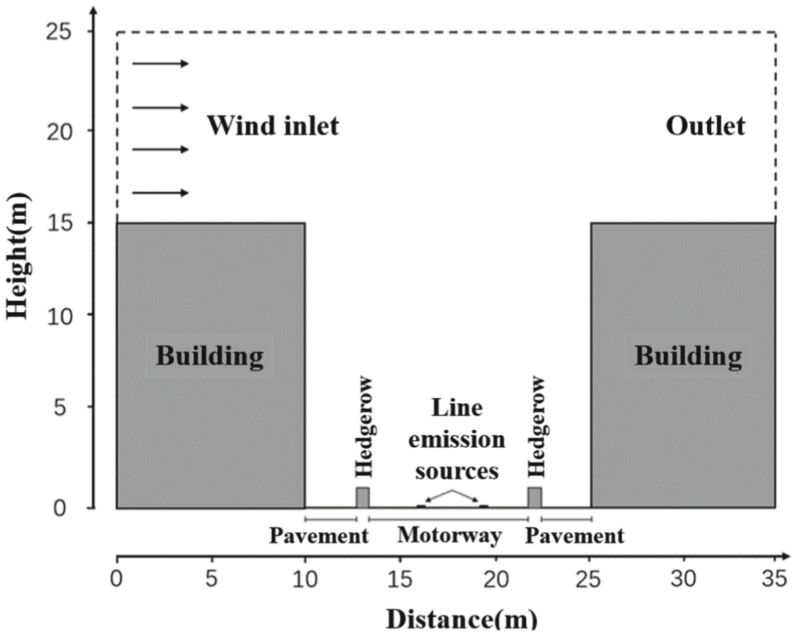

Fig. 1. Street canyon model

Tong's research shows that at low wind speeds, solid vegetation barriers (solid barriers covered by vegetation) have a similar effect on the diffusion of traffic emissions [3]. Gromke, C. and Gallagher, J.'s study also showed that dense leafy vegetation barriers can be simulated as solid barriers [4, 5]. Considering that urban street shrubs are mostly dense leafy vegetation, hedgerows are modeled as solid barriers in this study.

This study explores hedgerow appearance effect on the spread of CO, so on shrub shape, as shown in the hedgerow appearance is conducted on the basis of original form a slope cutting, the cutting and chose not to extend upwards, because extended upward and structural slope changed the original hedgerow size and impact of the results will not be of research significance, And cutting processing is more practical, to the future of urban road reconstruction to provide practical convenience. In this study, hedgerows were given three slope angles, 15°, 30° and 45°. Hedgerow model is shown in Fig. 2.

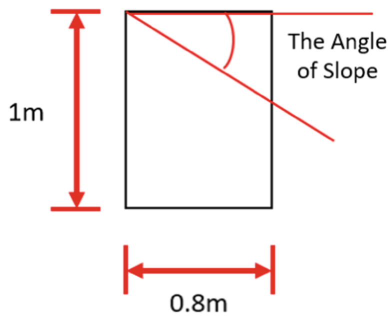

Fig. 2. Schematic diagram of hedgerow

2.2 Boundary Conditions

The wind inlet is set to 2 m/s. Pollution source emissions refer to the estimation of road vehicle exhaust and non-exhaust emissions by Nagpure [6], and the order of magnitude $1e^{-5}$ m/s of CO emission rate is taken as the inlet speed of CO line source in accordance with the actual situation. Some parameters of numerical simulation are shown in Table 1.

Table 1. Summary of key parameters in numerical simulation

Type	Name		Value	Unit
Street canyon	Configuration	Aspect ratio	1	
Meteorology	Wind	Velocity	2	m/s
		Direction	90	°
	Temperature		27	°
Vegetation	Hedgerows	Slope	0,15,30,45	°
		Height	1	m
		Width	0.8	m
Pollutant (CO)	Emission source	Velocity	$1e^{-5}$	m/s
		Mass	12.5	mg/s

3 Results and Discussion

When the valley of the wind direction is perpendicular to the street, because of the impact of buildings on both sides, valley street within a large clockwise vortex, flow diagram as shown in Fig. 3, valley street, is similar to a square cavity, because of the effect of flow field, the upstream building lee windward surface contaminant concentration is higher than the downstream building the concentration of the pollutants, and contaminants gathered in the leeward side corner, cannot efficiently, This is how pollutants spread in street Canyons, and hedgerows on both sides of the road can effectively reduce the concentration of pollutants at sidewalk breathing level.

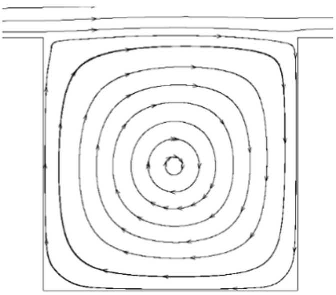

Fig. 3. Flow field in street Valley

Figure 4 (a), (b), (c) and (d) were isographs of CO mass fraction in street-valleys when the wind speed was 2 m/s for hedgerows with slopes of 0°, 15°, 30° and 45°, respectively, showing CO diffusion in street-valleys. As can be seen from Fig. 4, CO diffusion was better in the other three street-valleys with sloping hedgerows than in the original ones. The overall concentration of CO in street-valleys was lower, especially the 30° sloping hedgerows, which had the best effect on CO diffusion.

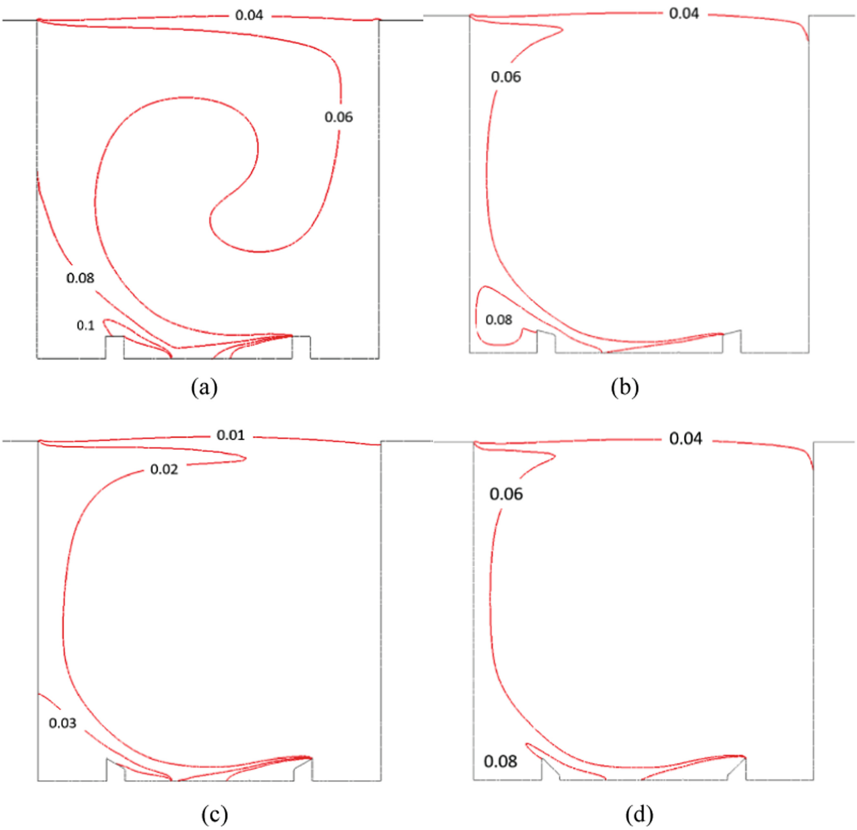

Fig. 4. Isogram of pollutant mass fraction at 2 m/s wind speed

As can be seen from the wind speed vector diagram in Fig. 5, after slope modification of hedgerows on the leeward side, the blocking effect of the central vortex on the street valley is weakened. The slope of hedgerows is close to the edge of the central vortex, so the wind speed of the central vortex there will not be weakened due to the blocking of hedgerows. As can be seen from the wind speed cloud in Fig. 6, in the leeward side of buildings where pollutants gather, the maximum wind speed here is 0.7 m/s in the street valley with common hedgerows, while it can reach 0.9 m/s in the street valley with sloping shrubs.

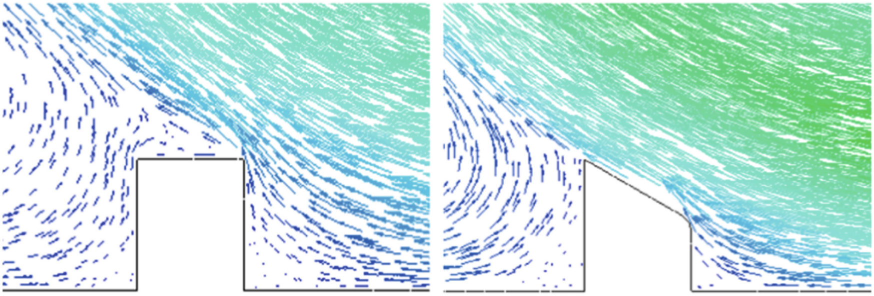

Fig. 5. Velocity vector diagram of leeward pavement at 2 m/s wind speed

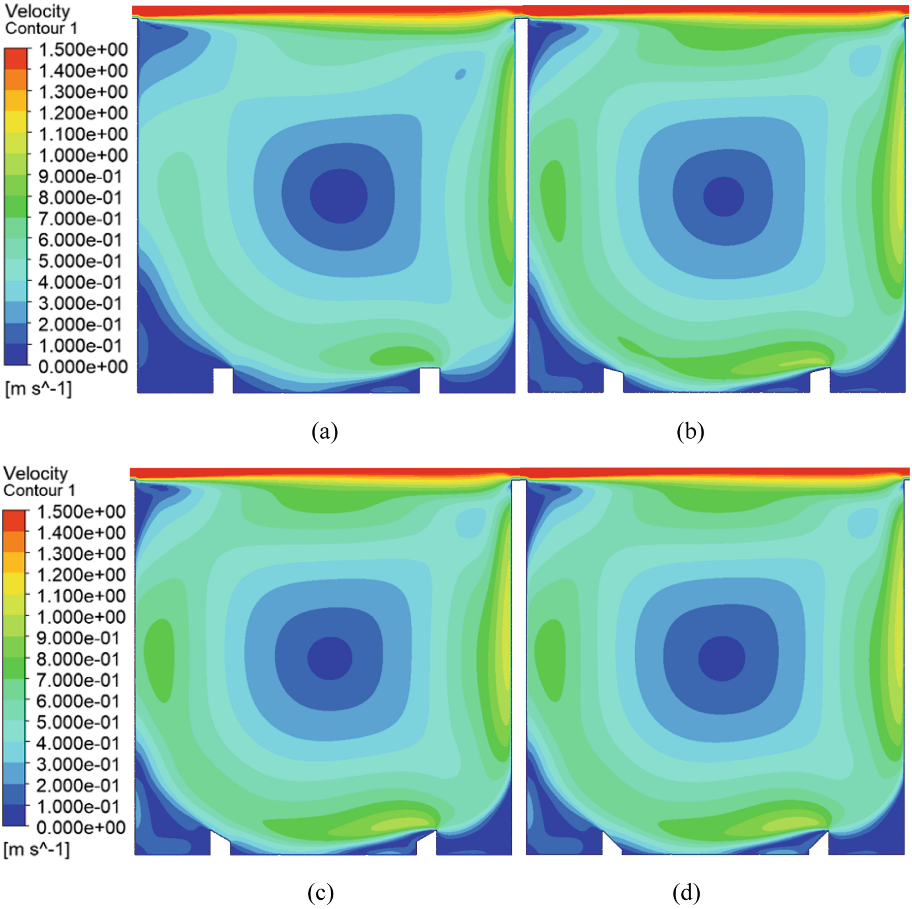

Fig. 6. Cloud chart of wind speed in street Valley at 2 m/s wind speed

In the leeward side near the ground, because of the influence of the valley center of vortex street, will form a low-speed counterclockwise vortex, here in Fig. 7, you can see, because the hedgerow with slope surface better fit the center of the edge of large vortex street and the make the center edge vortex wind speed increase, thus speeding up the leeside sidewalk anticlockwise vortex edge at low speed wind speed, As a result, the overall wind speed of the low-speed vortex increases. The wind speed on the left side of the vortex is 0.15 m/s in the no-slope shrub street canyons, but it can increase to 0.2 m/s in the 15° and 45° shrub street canyons, and to 0.25 m/s in the 30° shrub street canyons. Below the vortex, the wind speed increased from 0.1 m/s to 0.2 m/s after increasing the shrub slope.

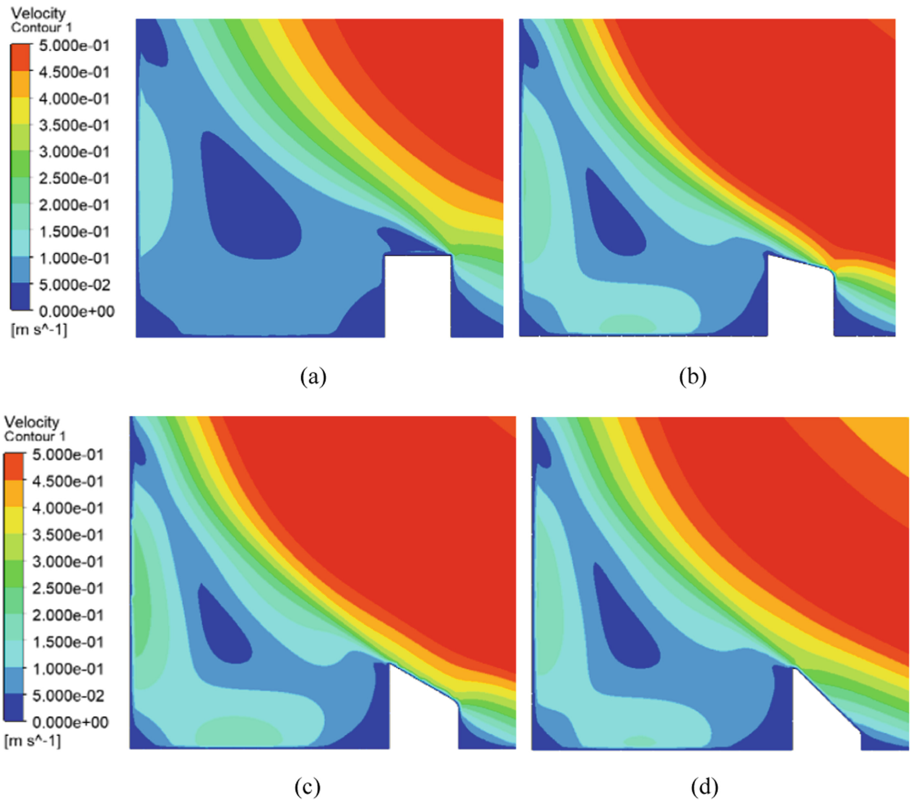

Fig. 7. Velocity cloud chart of leeward pavement at 2 m/s wind speed

As can be seen in the flow diagram in Fig. 8, the vortex center moved down 35 cm in the 15° hedgerow street valley, 40 cm in the 30° hedgerow street valley, and 38 cm in the 45° hedgerow street valley. The area of low-speed vortex decreases as the wind speed at the vortex edge increases. Therefore, CO gathered in the leeward corner can better diffuse out of the street-valley with the rise of eddy wind speed. Therefore, after the slope modification of the original hedgerows, the wind speed of the flow field in the whole street-valley is increased to a certain extent, thus speeding up the air circulation inside and outside the street-valley, and thus facilitating the better discharge of CO.

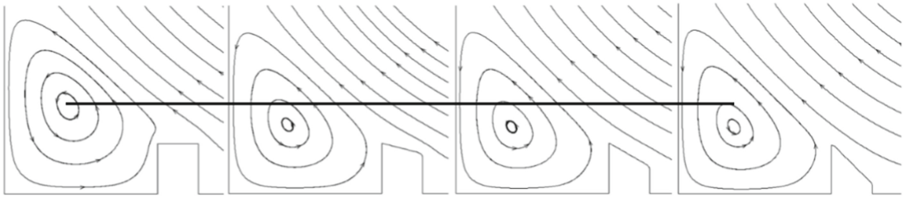

Fig. 8. Streamline diagram of leeward pavement at 2 m/s wind speed

Measuring points were arranged along the vertical height at 5 cm on the wall of the building on the leeward side of the street valley and 5 cm above the ground, with a spacing of 0.25 m. In Fig. 9, the CO mass fraction at the vertical height of the leeward building wall decreases slowly with the rise of the height. In street canyons with sloping hedgerows, the mass fraction of CO at building walls was lower. Under the influence of 15° hedgerows and 45° hedgerows, the CO concentration at the wall was lower, by 14% and 21%, respectively, and in the street valley of 30° hedgerows, the CO concentration at the wall decreased by 70%. Effectively improve the window ventilation environment of the residents in the lee. Measuring points were arranged horizontally at the pedestrian height (1.7 m), with a spacing of 0.25 m. In Fig. 10, the CO mass fraction at the pedestrian level of street valley (1.7 m) from the leeward side to the windward side. Due to the flow field, CO emissions from street vehicles concentrated near the leeward hedgerows, so there was a rising stage and then a decline. It can also be seen that in the 15° and 45° hedgerows, the CO concentration at the pedestrian level was lower than in the normal hedgerows, by 14% and 21%, respectively. In the 30° hedgerows, the CO concentration at the pedestrian level decreased by 70%.

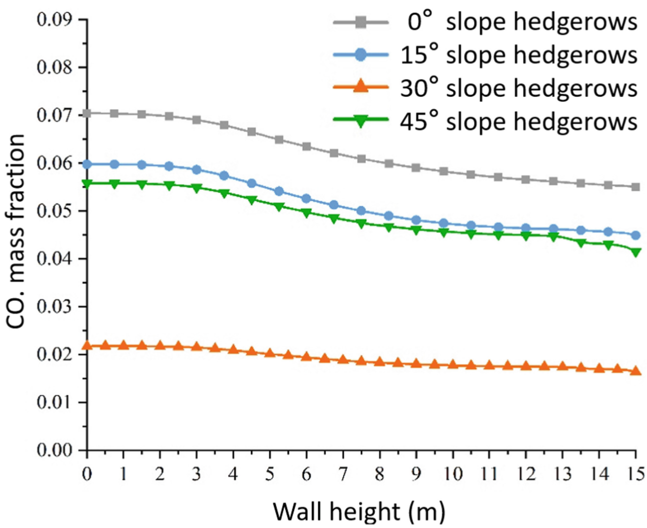

Fig. 9. Line chart of CO mass fraction at vertical height of leeward wall

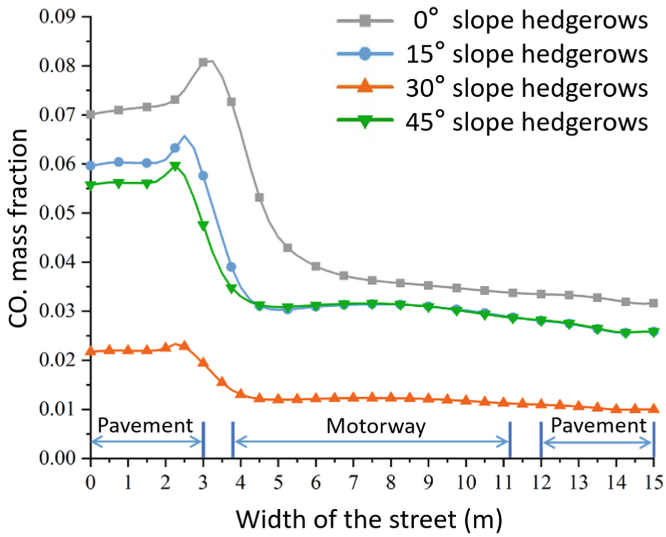

Fig. 10. Line chart of CO mass fraction at the level of 1.7 m pedestrian walk

4 Conclusion

(1) In the street-valleys with sloping hedgerows, the wind speed of the whole vortex is higher than that of the original hedgerows. Under the influence of the flow field, pollutants in the street-valleys can be effectively removed and the overall concentration in the street-valleys is lower.

(2) because of the influence of the hedgerow, in the leeward side near the ground will be a low vortex, lead to CO gathered here, hedgerow with slope surface of street in the valley, lee side near the ground vortex wind speed is greater at low speed, smaller, closer to the ground and vorticity center, that had gathered near the sidewalk CO to better spread.

(3) Among the hedgerows with slopes of 15°, 30° and 45°, the hedgerows with slopes of 30° had the best diffusion of pollutants in street-canyons. Compared with the street-canyons with original hedgerows, the CO concentration near the wall and at pedestrian height decreased by 70%.

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