Analysis on the Effect of Different Driving Conditions on Dispersion of Vehicle Exhaust Based on Fluent

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Abstract: ***To study the difference of the dispersion of vehicle exhaust (carbon monoxide, CO) under different driving conditions, namely, idling, constant speed, uniform acceleration, uniform deceleration, uniform acceleration followed by uniform deceleration and uniform deceleration followed by uniform acceleration, a numerical simulation was designed and performed by using a multipurpose commercial fluid dynamics software Fluent in this study. The relative deviations of CO concentration under different driving conditions were calculated and compared with treating the driving condition of constant velocity as benchmark. It was shown that the maximum relative deviation can be reached as high as 39%, which demonstrates that the effect of driving conditions on the dispersion of vehicle exhaust cannot be neglected especially during the prediction of the concentration of the pollutant in the street canyon.***

Keywords: Vehicle exhaust dispersion, Driving conditions, Numerical Simulation, Fluent

1. Introduction

With the continuous advancement of urbanization, automobile exhaust has become one of the main sources of urban air pollution. Especially in the environment of urban street canyons with features of poor natural ventilation, it further exacerbates the harm resulted from vehicle exhaust to the pedestrians and residents near the street. Fortunately, the reasonable urban planning and proper traffic control contribute to the mitigation of the problem, and all of these are based on the understanding of the dispersion rules of pollutants in the urban street canyons. At present, a large number of researchers have studied the dispersion rules of vehicle exhaust in the street canyons from different influencing factors which includes the geometric structure and layout of the street canyons [1-3], meteorological conditions [4-7], urban tree planting [8-9] and vehicle's motion [10-12].In the study of factors of vehicle's motion, the vehicle-induced turbulence is often used to quantify the effect of vehicle's motion on the dispersion of pollutants. In this process, the average speed of vehicle, traffic volume and density of vehicles are the focuses and the driving conditions (idling, uniform speed, acceleration, etc.) are always neglected. In detail, in the previous studies, researchers only concerned on how the driving conditions affect the strength of the vehicle exhaust and treated the driving condition as the default motion of constant velocity.

2. Methodology

2.1 Design of simulation background and vehicle driving condition

Since driving condition is the only variable in this paper to study the dispersion of vehicle exhaust and for avoiding the interference from other factors that may affect the process of pollutant dispersion. The following simulation background and assumption are adopted.

First of all, the effects of temperature and chemical reaction were ignored in this study

Secondly, the background concentration of the pollutant and the ambient wind speed were treated as zero.

Besides, the release of vehicle exhaust is steady and the same during the whole driving process under different driving conditions.

Finally, five moving vehicle driving conditions (numbered v1-v5) with the average speed of 5 m/s and one idling driving condition with speed of zero (numbered v0) were designed and modeled in this study. As shown in Table 1 and Figure 1, the time-velocity functions and curves of the six driving conditions are presented respectively. In detail, case V0 represents the driving condition of idling; case v1 represents the driving condition of constant speed; case v2 represents the driving condition of uniform acceleration, case v3 represents the driving condition of uniform deceleration; case v4 presents the driving condition of uniform acceleration followed by uniform deceleration and v5 represents the driving condition of uniform deceleration followed by uniform acceleration.

Table 1 Mathematical expression for driving conditions

Driving conditions	*Time-velocity functions*
idling（v0）	v0=0 （0≤t≤4)
constant speed（v1）	v1=5 （0≤t≤4)
uniform acceleration（v2）	v2=2.5t （0≤t≤4)
uniform deceleration（v3)	v3=-2.5t+10 （0≤t≤4)
uniform acceleration followed by uniform deceleration（v4）	v4=-5t+20 （0≤t≤2)
	v4=5t （2≤t≤4)
uniform deceleration followed by uniform acceleration (v5)	v5=-5t+10 （0≤t≤2)
	v5=5t-10 （2≤t≤4)

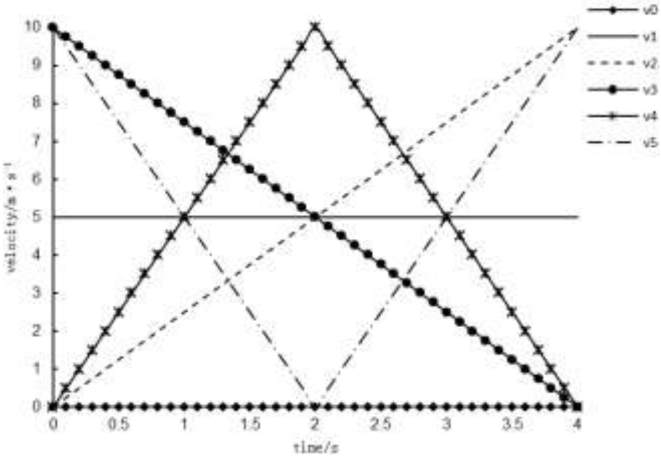

Figure 1: The relationship between velocity and time for different driving cycles

2.2 Setup of numerical modeling

In this paper, a 2-d computational domain of rectangle plane with scope of 39.165 m * 7 m as it is shown in Figure 2 is used to perform the simulation of dispersion of vehicle exhaust under various driving conditions.

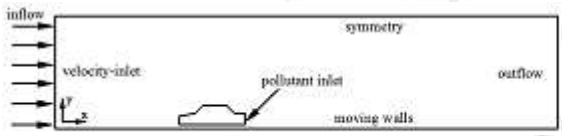

Figure 2: Computational domain and boundary conditions

The left side of the computational domain is the flow velocity inlet, which is used to model the various driving conditions while keep the car stationary during the simulation based on the thought of relative movement [11]. The top of the computational domain is the symmetric boundary. The bottom of the domain is the moving walls with no shear stress. The right side of the domain is outflow boundary condition. The vehicle exhaust was simulated by the gas mixture of carbon monoxide (CO) and air, in which the volume fraction of carbon monoxide is forty present, and it is released as the velocity of 10 m/s. Besides, the Standard k- epsilon model with standard wall function was used to model the turbulence of the flow. Finally, the transient pressure-base solver with SIMPLE algorithm for the coupling of pressure and velocity was selected for the total four seconds running in this study.

3. Results and Discussion

In this paper, the spatial distribution of the concentration of CO will be used to analyze the difference of the pollutant dispersion under various driving conditions. As shown in Figure 1, different instantaneous velocity can be found for different driving conditions. As a result, in order to ensure the average velocity of the various driving conditions is the same (5 m/s), the results from the point in time at the end of the fourth second are selected. As shown in Figure 3, a sampling domain of the scope of 20 m×3 m behind the car with 147 sampling points is selected to present the concentration of the pollutant. These sampling points can be further divided into seven groups based on their heights from 0 m to 3 m to represent different sampling planes, namely, the plane y=0, y=0.5, y=1.5..., y = 3. At the rest of the paper, the average concentration of CO at both the different sampling planes and the whole sampling area will be studied and compared for all driving conditions respectively.

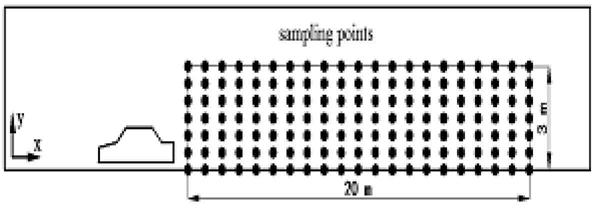

Figure 3: Sampling points for the concentration of CO

First of all, the average concentrations of CO from different sampling planes under various driving conditions are presented in Figure 4. It could be found that the concentration of CO gradually decreases with the increase of the height for all the driving conditions, which means that CO tends to accumulate in the near-surface area at the end of the fourth second after the vehicle' moving. However, the speed of the decrease of the concentration varies from different driving conditions and the steep decline appeared at the driving conditions of constant speed and uniform acceleration (v1 and v2) from the height of 0.5 m to 1.5 m. The maximum concentration of CO (6.38%) appeared at the planes of y = 0 m and y = 0.5 m under the driving conditions of idling case (v0) and constant speed case (v1),respectively. It is worth to mention that in the previous studies, researchers always neglects the effect of the driving conditions on the dispersion of pollutant, which means that the only driving condition of constant speed was used to replace all the other driving conditions. In order to quantify the error may be caused by this action, The relative deviations (di) of CO concentration under different driving conditions were calculated (equation 1) and compared with treating the driving condition of constant velocity (v1) as benchmark in this paper.

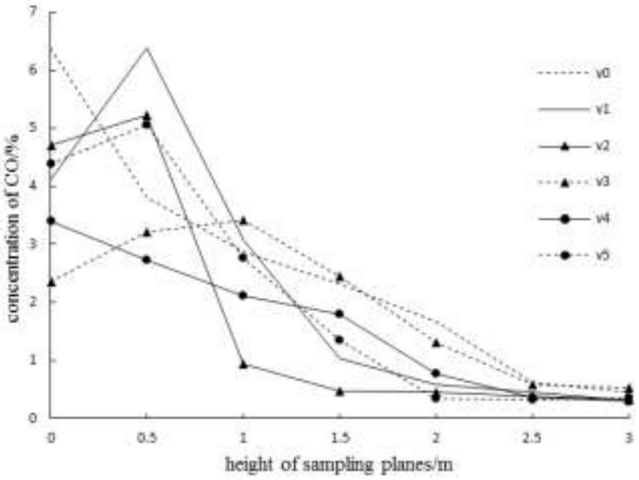

Figure 4: Average concentration of CO for six driving cycles under different sampling planes

$$d_i = \frac{c_1 - c_i}{c_i} \times 100\% \qquad (1)$$

Where, di is the relative deviation of CO concentration for the i-th driving condition vi (i = 2, 3 and 4), c1 is the concentration of CO from driving condition of constant speed (v1) and ci is the concentration of CO from the driving condition of case i

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(vi). It is worth noting that the relative deviation di can be seen as the error that would be aroused by replacing other driving conditions (v2-v5) with the driving condition of constant speed (v1). The relative deviations for various driving conditions based on different sampling planes are presented in Figure 5. It was shown that a large proportion of positive deviation could be found in the area near the surface (the planes of y=0 m, 0.5 m and 1 m), which means that the concentration of CO would be overestimated if the constant speed driving condition (v1) was used to replace the other driving conditions (v2-v5).The maximum positive deviation (229%) appeared at the sampling plane of y= 1m under the driving condition of uniform acceleration (v2). Besides, in contrast, a large percentage of negative deviation could be found in the higher sampling planes of y=2 m, 2.5 m, 3 m, which means that the concentration of CO would be underestimated if the constant speed driving condition (v1) was used to replace the other driving conditions (v2-v5) and the maximum negative deviation (-58%) could be found at the sampling plane of y= 1.5 m under the driving condition of uniform deceleration (v3).

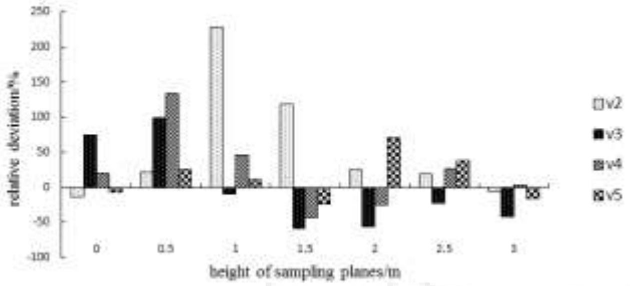

Figure 5: The relative deviation of average CO concentration between driving conditions of v2-v5 and v1 under different sampling planes

If we extend the study object from the sampling planes to the whole sampling domain, the results may be different. The average concentration of CO and its relative deviation for various driving conditions cover the whole sampling domain were presented in Table 2. It can be found that the driving condition of idling (v0) experienced the maximum concentration of CO (0.0259%), which corresponds to the worst condition for the diluting of the pollutant. It demonstrated that the movement of vehicle is benefit to the dilution of the pollutant. Besides, among the driving conditions of vehicle moving (v1-v5), the cases of constant speed and uniform deceleration experienced the maximum (0.0228%) and minimum (0.0164%) concentration of CO respectively. In terms of relative deviation, all the positive values could be found for the moving driving conditions (v2-v5), which means that the concentration of CO would be overestimated if the constant speed driving condition (v1) was used to replace the other driving conditions (v2-v5) and the maximum value (39%) appeared at the driving condition of uniform deceleration (v4). From the perspective of safety, it is reasonable to replace the driving conditions (v2 -v5) of favorable dilution with that of unfavorable dilution when we try to make a decision to abate the negative effect resulted from the high pollutant concentration. However, from the perspective of the accuracy of predicting the dispersion of pollutant, the error may be unacceptable as it can be reached as high as 39%.

Table 2: The average CO concentration and its relative deviation of different driving cycles for all sampling points

Driving conditions	*v0*	*v1*	*v2*	*v3*	*v4*	*v5*
Concentration of CO/%	0.0259	0.0228	0.0179	0.0198	0.0164	0.0209
Relative deviation/%	-12.16	0.00	27.41	15.14	39.02	9.25

4. Conclusion

The effects and differences on the dispersion of vehicle exhaust under various driving conditions were studied in this paper by using the method of numerical simulation. It was shown that (a) compared to the driving condition of idling, the movement of the vehicle is benefit to the dilution of the pollutant; and (b) the relative deviation caused by replacing the various driving conditions with the driving condition of constant speed can be reached as high as 39%, which demonstrates that the effect of driving conditions on the dispersion of vehicle exhaust cannot be neglected during the process of predicting the pollutant concentration in the street canyon.

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