Dynamic Changes and Analysis of Air Quality in Private Cars

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Abstract. This paper selects CO2, formaldehyde and VOC as pollutants, and dynamically tests the concentration of CO2, formaldehyde and VOC in different ventilation modes, different seasons, different road conditions and different purification methods to explore the change of pollutant concentration and its influencing factors under different working conditions. According to the dynamic test results, more representative formaldehyde was selected. The breathing height Z=0.75m section was used as typical section. Simulation conditions are divided into: different air supply speed, different air supply temperature. The results show that the concentration of formaldehyde / VOC is the highest in summer, the lowest in excessive season, higher in crowded road conditions, the highest of CO2 in excessive season and the lowest in summer. Concentration of pollutants is relatively ideal in open-window ventilation and air conditioning external cycle. The use of activated carbon and vehicle purifier in the vehicle can play a certain purification effect, among which the purification effect of vehicle purifier is better. Higher air supply speed and lower air temperature will reduce formaldehyde concentration.

1. Introduction

People's daily life, work and travel cannot do without cars. The human body is exposed to the microenvironment in the car for more and more time. However, compare the results of air quality in other areas, the microenvironment in the vehicle needs to be explored. As early as 1988, scholars C.C.Chang in North Carolina, the United States, cars in different driving conditions and different external environment of the test of pollutants, The measured value of VOC concentration in urban road environment is more than 10 times \(^{[1]}\) that of rural road. In 2008, Wang Xiaoge and others in four months to 17 bus cars, Testing of volatile organic compounds in more than 30 new vehicles in sales stores, Only 2 of the 50 vehicles did not exceed the formaldehyde limit \(^{[2]}\) of the GB50325-2011 Environmental pollution Control Code. The U.S. Environmental Protection Agency (EPA) classifies car pollution as a "mobile pollution source" \(^{[3]}\), The so-called "driving syndrome" is also closely related to these pollutants \(^{[4]}\). In this paper, the dynamic monitoring of air quality in domestic vehicles is carried out, simultaneously using CFD numerical simulation technique is used to study the spatial distribution of pollutants, and relevant conclusions are put forward.
2. Dynamic monitoring

2.1. Location of measuring points
During sampling, the corresponding probe is fixed at the same height as the head of the driver, and the CO2, VOC test probe is near the middle position in the front seat; the formaldehyde test probe is near the middle position in the back seat to simulate the respiratory intake height of the human body to pollutants.

2.2. Test conditions and counting methods
The test sections are: ordinary section, crowded section; test season is divided into summer, winter, excessive season; ventilation mode is divided into: window ventilation, air conditioning internal circulation, air conditioning external circulation[5]; purification mode is: activated carbon adsorption, Vehicle purifier purification. Counting method: the test instrument is set to record one data every 5s, continuous testing 4 min and final value of this set of data is the average within 4 min. A total of 5 groups of continuous testing, that is, the total duration of a working condition test is 20 minutes.

2.3. Recommended concentration standard values for each pollutant vehicle

| Pollutant       | CO2     | VOC      | Formaldehyde |
|-----------------|---------|----------|--------------|
| Recommended concentration values | 2000ppm | 0.6 mg/m³ | 0.12 mg/m³ |

3. Test result

Figure 1 shows the CO2 concentration in different ventilation modes in summer. The order from high to low is: activated carbon+air conditioning internal circulation>air conditioning internal circulation>purifier+air conditioning internal cycle>activated carbon+air conditioning external circulation>purifier+air conditioning external circulation>air conditioning external circulation>open window ventilation. The figure shows that the internal circulation of air conditioning is obviously higher than that of external conditioning of air and its maximum concentration has been above 4500ppm within 20 minutes. The CO2 concentration in the window ventilation condition is about 500ppm in 20 minutes. The activated carbon working condition will increase the CO2 concentration value[6]; the purifier itself do not deal with CO2, however, the use of the purifier will speed up the flow of airflow in the vehicle and make the test results relatively low.

Figure 1 shows that CO2 concentration in the air conditioning under the internal circulation condition is obviously higher than that of the air conditioning external circulation and the window opening ventilation condition. Therefore figure 2 selects the internal circulation conditions of air conditioning under different seasons. Conclusion: excessive season > winter > summer. We can see
that the maximum CO₂ concentration of excessive season can reach 5000ppm, higher than that of other seasons, because of different seasons, the carbon dioxide produced by human respiration is different. And CO₂ concentration in the car is the least in summer.

Figure 3 shows the concentration of VOC in different ventilation modes: air conditioning internal circulation>air conditioning internal circulation + activated carbon>air conditioning internal circulation + purifier>air conditioning external circulation + activated carbon>air conditioning external circulation + purifier>open window ventilation. The figure shows that the concentration of VOC in the vehicle is the lowest and the stability is below 80 ppb when the window is ventilated. Air conditioning internal circulation of the maximum concentration of up to 200 ppb. The vehicle purifier and activated carbon play a certain role in purification, in which the effect of the vehicle purifier is better. The vehicle VOC can be kept between 100 ppb-120ppb within 20 minutes when the air conditioning internal circulation is used.

Figure 4 selects the air conditioning internal circulation condition with the largest concentration in VOC under different ventilation conditions, and compares the difference of its concentration in different seasons. Figure 4 shows, Summer > winter > excessive season; this is because the VOC emission is proportional to the temperature in the car, the highest temperature in summer, the second in winter, the lowest temperature in the car due to the lack of air conditioning heating; excessive season to open air conditioning internal circulation, the VOC concentration in the car is stable below 125 ppb; summer air conditioning internal cycle VOC concentration up to 200 ppb.

Figure 5 shows the concentration of formaldehyde in different ventilation conditions in normal road conditions. It can be seen that the lowest formaldehyde content in the vehicle is when the window is ventilated, within 20 minutes, the average value of formaldehyde in the vehicle remained between
0.04 ppm-0.5ppm, the formaldehyde content in the vehicle was relatively large during the internal circulation of air conditioning, the maximum value could reach 0.83 ppm, and there was little difference between using activated carbon and vehicle purifier.

Figure 6 shows the concentration of formaldehyde in different ventilation modes in congested road conditions, it can be seen that the formaldehyde content of any ventilation mode in crowded road conditions is higher than that in general. The difference is that the formaldehyde content in the external circulation of air conditioning is larger than that in the internal circulation of air conditioning, and even the phenomenon of formaldehyde exceeding the standard occurs. The mean value of formaldehyde in the vehicle during the internal circulation of window opening ventilation and air conditioning is similar, but the concentration of formaldehyde in the vehicle is more stable when the window is ventilated, and the minimum content in the vehicle is when the internal circulation of air conditioning is combined with the vehicle purifier.

4. CFD numerical simulation

4.1. Introduction to Physical Models
Figure 7 shows the side view of the physical model used in this experiment. The ratio of the size to the actual size of the sample vehicle is 1:1, and the physical model is equipped with 9 tuyere, which are: 1 inlet in front of the car, 2 return tuyere in front of the car, 2 in the rear of the car and 4 windows.

![Simulated physical model](image)

4.2. Introduction to Physical Models
The boundaries considered in the simulation include: air inlet, air outlet, personnel, sofa, ceiling, window, body, car bottom. The air inlet is the speed inlet, the air conditioning air supply speed is 2m/s, the window opening ventilation speed is 5m/s, the air conditioning air supply temperature is 295K, the window opening ventilation temperature is 308 K; the air outlet is the pressure outlet, the gauge pressure is 0Pa; the vehicle personnel is the moving heat dissipation element, the heat flux is 20W/m²; the sofa is the mass flow inlet, the emission rate is 2.5×10⁻⁸kg/s, the ceiling, the window, the body, the car bottom is the constant heat source, the wall surface temperature is 318 K, 316K, 310K, 305K.

5. Numerical simulation results analysis

![5m/s ventilation rate](image) ![3m/s ventilation rate](image) ![2m/s ventilation rate](image)

When the air supply speed of air conditioning is 5 m/s, 3m/s and 2m/s, the cloud distribution of formaldehyde in the interior space of the vehicle is given in figure 8-figure 10. It can be seen that when other conditions remain unchanged only change the ventilation speed, the area where
Formaldehyde is easy to accumulate in the space is generally unchanged; the larger the air supply speed, the less formaldehyde is distributed in the space and the smaller the scattered area. On the contrary, the smaller the air supply speed, the more formaldehyde is distributed in the vehicle space, and the larger the area is scattered.

Figure 11-13 shows the cloud distribution of formaldehyde in vehicle space when the air supply temperature is 290 K, 295 K, and 300 K. It can be seen that when other conditions remain unchanged, only the air supply temperature of air conditioning is changed; the higher the temperature, the more the distribution of formaldehyde in space, the larger the area of scattered area; on the contrary, the lower the ventilation temperature, the less the distribution of formaldehyde in space.

6. Conclusions
At different seasons CO₂ concentration in the car was the largest in the excessive season, followed by winter and the smallest in summer, formaldehyde/ VOC concentrations were highest in summer, second in winter and minimum in excess season; at different ventilation modes CO₂, formaldehyde and VOC the concentration in the vehicle is the largest in the internal circulation of air conditioning, and the minimum in the ventilation of windows. (In crowded traffic, formaldehyde / VOC concentration is higher than other working conditions in the external circulation of air conditioning). Air-conditioner internal circulation conditions, no matter any season the pollutant is double growth; windows should be used to ventilate or air conditioning external circulation instead of long air conditioning internal circulation. The effect of vehicle purifier on treating pollutants is better than that of activated carbon, it is not recommended that activated carbon be used to treat pollutants when passenger is crowded.

From the distribution in the space, the higher the air supply temperature, the larger the space of formaldehyde dispersion, the more the amount of formaldehyde dispersion, the smaller the air supply speed, the larger the space of formaldehyde dispersion more the amount of formaldehyde dispersion. Therefore, the air supply temperature can be used to meet the minimum temperature value in the range of thermal comfort temperature in the vehicle, and the air supply speed can be used to meet the maximum speed in the range of comfortable blowing feeling of the personnel in the vehicle.

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