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Influence of Environmental Factors and Vehicle Factors on VOC Volatilization Characteristics in Automobiles

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From the two aspects of external environmental factors and vehicle factors, this paper studies the influence of in-car temperature, humidity, vehicle type, vehicle mileage, vehicle exhaust displacement and other factors on the harmful volatile organic compounds (VOC) in the automobiles. The research results show that: in terms of external environmental factors, the increase of temperature and relative humidity in the car will cause the in-car VOC concentration to increase, and the temperature has a more significant influence on the VOC concentration in the car; being in area with poor environment and serious exhaust emissions for a long time will increase the VOC concentration in the car; when the natural wind speed increases, the concentration of VOC pollutants in the car gradually decreases. In terms of vehicle factors, the VOC concentration in high-end cars is significantly higher than that in low-end cars, and the VOC concentration of new cars is higher than that of old cars. As the car age and mileage increase, the VOC concentration in the car begins to decrease. The vehicle exhaust displacement is proportional to the VOC concentration in the vehicle, and the interior space is inversely proportional to the VOC concentration. The influence of the change in the interior space on the harmful VOC concentration is relatively small.

1. Introduction

With the increasing of car ownership, the problem of air pollution inside the car has gradually received more attention from the public (Chien, 2007; Buters et al., 2007). According to research, the pollution inside the car is mainly caused by the volatile organic compounds (VOC) generated by the interior decoration materials. Staying in this environment for a long time will cause dizziness, fatigue, nausea and other symptoms, and even lead to various diseases to the human respiratory system and immunity system (Xu et al., 2016; Kim, Dominici and Buckley, 2007; Riediker et al., 2003; Liu et al., 2015). Studying the diffusion law of VOCs in the car and controlling in-car VOC pollution has become the focus of current research (Yoshida et al., 2006; Dominici et al., 2006; Tatsu et al., 2016; Faber, 2015).

At present, automobile interior decoration materials include various resin materials, chemical fillers, etc., and VOC types in the car include formaldehyde, benzene organic compounds, undecane, n-butyl acetate, etc. (Geiss et al., 2009; Chen et al., 2014; Zhang et al., 2008). At present, the research on the VOC diffusion law in the car (Jiang, Xiao and Liang, 2011) mainly includes the in-car VOC pollution degree survey, the car pollution health risk assessment, and the influence of vehicle-related parameters (mileage, car age, interior decoration type, in-car space volume, etc.) on the characteristics of VOC volatilization (Fedoruk and Kerger, 2003; Chen et al., 2016; Hsu and Huang, 2009; Batterman et al., 2006). However, the current research results have large differences in the in-car VOC concentration statistics, there is no general conclusion, and the investigation of vehicle-related parameters is not comprehensive (Yoshida and Matsunaga, 2006).

This paper considers from the two aspects of external environmental factors and vehicle factors, studies the influence of in-car temperature, humidity, vehicle type, vehicle mileage, vehicle exhaust displacement and other factors on the harmful (Wang et al., 2018) VOCs in the automobiles. The research conclusion can provide a theoretical reference for the volatilization detection and control of VOC in the car.

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2. Influence of environmental factors on VOC diffusion law in the car

First, the influence of environmental factors on the VOC diffusion law in the car is analyzed. Figure 1 shows the concentration change of various VOCs in the car at different temperatures. As can be seen from the figure, the temperature inside the car is proportional to the concentration of various VOCs in the car. When the temperature inside the car increases from 24°C to 36°C, the concentration of benzene organics in the car increases by about 3.85 times on average; The concentration of n-butyl acetate and undecane increases by 4.5 times and 6.5 times, respectively; the total organic matter content (TVOC) in the car increases by about 3.7 times.

Automobile interior decorative materials would occur complex chemical changes under high temperature, including volatilization and decomposition of chemical additives. Therefore, the interior of the car should be protected from the sun exposure.

Figure 2 shows the concentration change of various VOCs in the car at different relative humidity. It can be seen from the figure that when the relative humidity increases, the concentration of various VOCs in the car also tends to increase gradually, but the influence of relative humidity on the VOC is not as obvious as the temperature. In-car humidity increase will cause VOCs to dissolve in the water vapor and reattach to the surface of the car's decorative material, causing secondary pollution.

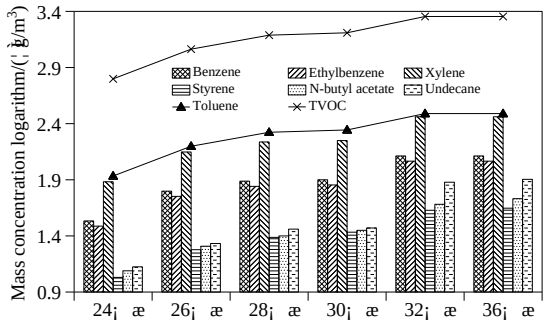

Figure 1: Concentration change of various VOCs in the car at different temperatures

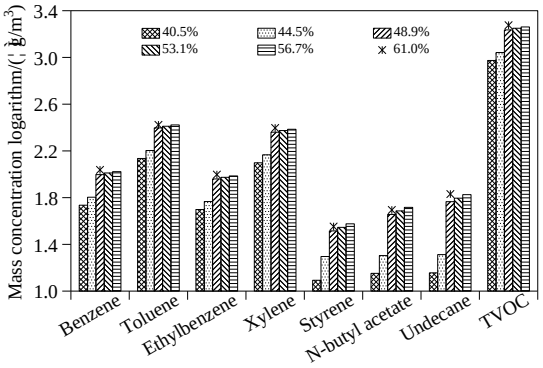

Figure 2: Concentration change of various VOCs in the car at different relative humidity

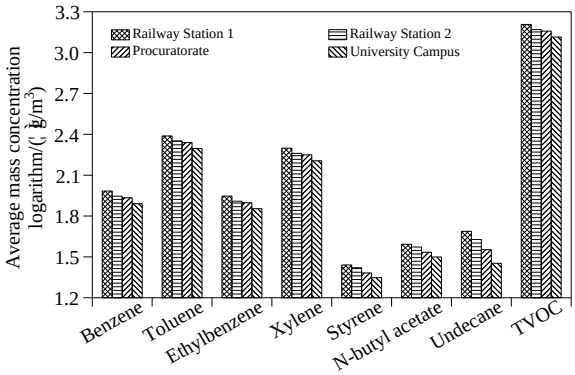

Figure 3: Concentration change of various VOCs in the car at different data collection locations

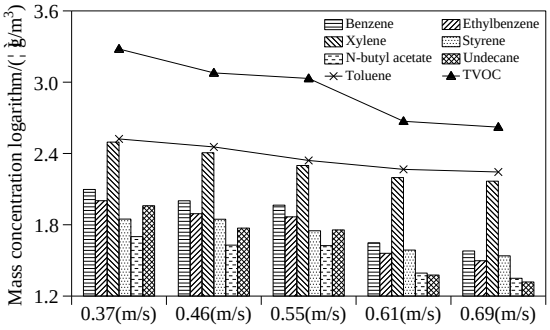

Figure 4: Influence of airflow on the concentration change of various VOCs in the car under natural wind mode

Figure 3 shows the concentration change of different VOCs in the car at different data collection locations. As can be seen from the figure, cars that are parked around railway stations have highest in-car VOC concentration, while cars that are parked on college campus have lowest in-car VOC concentration. The VOC concentrations at the four sampling locations are ranked from high to low as train stations, bus stations, procuratorates, and college campuses. It shows that the VOC pollution in the car is also heavier in areas with

poor environment, numerous vehicles and serious exhaust emissions, while VOC pollution in the car that are parked in area with better environment is relatively light.

Figure 4 shows the influence of airflow on the concentration change of various VOCs in the car under natural ventilation mode. It can be seen from the figure that when the natural wind speed increases from 0.37 m/s to 0.69 m/s, the concentration of VOC pollutants in the car shows a significant declining trend as a whole. When the natural wind speed is 0.69m/s, the concentration of toluene, ethylbenzene and styrene decreases by 48%, 68% and 59% respectively compared to the concentration of those when the wind speed is 0.69m/s; the concentration of n-butyl acetate and undecane decreases by 56% and 77%, respectively. This is because in the natural wind mode, the air exchange in the car is more frequent, which effectively diluted the VOC concentration in the vehicle.

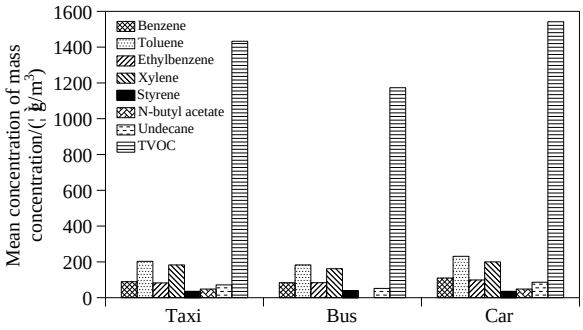

Figure 5: Changes in mean concentration of various VOCs in taxis, buses and cars

3. Influence of vehicle factors on the VOC diffusion law in the car

Figure 5 shows the concentration of various VOCs for different types of vehicles (taxi, bus, car). It can be seen from the figure that the VOC concentration values inside the three types of vehicles exceed the specified values of the relevant standard, and the VOC concentration values are ranked from large to small as cars, taxis and buses. The concentration of n-butyl acetate in cars is the highest, and the concentration of toluene in taxis is the highest.

The different types of cars are divided into high-end cars, mid-range cars and low-end cars according to price, rating and other factors. As can be seen from the figure, the VOC concentration ranks from high to low in order of high-end cars, low-end cars, and mid-range cars. There are many decorative materials in high-end cars, and the airtightness is the best, which causes various types of VOCs unable to be quickly released to the outside; the low-end cars generate a large amount of harmful VOC due to the use of more inferior materials. The concentrations of benzene, toluene and ethylbenzene in the mid-range cars were 78 μg/m^3, 198 μg/m^3 and 70 μg/m^3, respectively, which were all less than the values specified by the relevant standards.

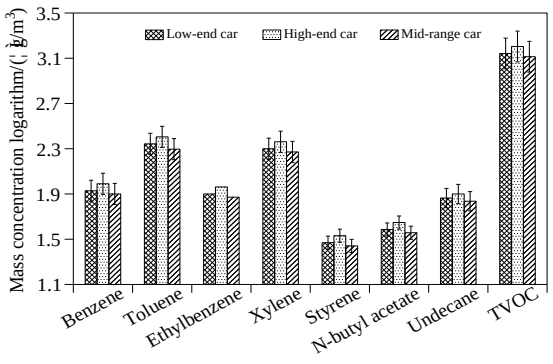

Figure 6: Changes in mean concentration of various VOCs in high-end, mid-range and low-end cars

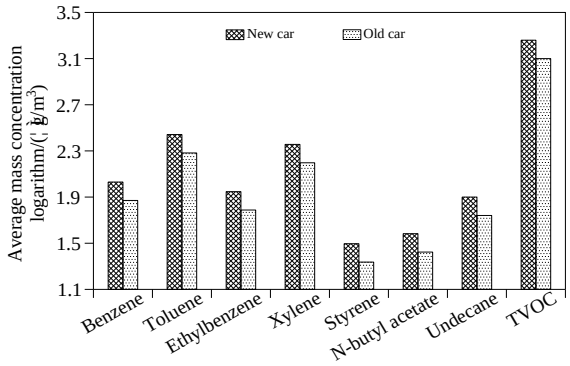

Figure 7: Influence of car age on concentration of various VOCs in the car

Taking the 12-th months after car leaving the factory as the dividing point, cars leaving the factory for less than 12 months are regarded as new cars, and cars leaving the factory for more than 12 months are considered as old cars. Calculate the concentration change of various VOCs in the two kinds of cars, as shown in figure 7. It

can be seen from the figure that, the concentrations of VOCs inside the new cars are all higher than those of the old cars. This is because the internal materials of the new cars are brand new, and the harmful VOCs stored therein will gradually volatilize, and the general volatilization period is more than 6 months.

Figure 8 shows the influence of car mileage on the VOC concentration in the vehicle. Similar to Figure 7, as the mileage of the car is increases, the concentration of harmful VOC stored in the interior decoration material gradually decreases, and the pollution inside the car is also reduced. According to the statistical results of this paper, when the mileage exceeds 140,000 km, the VOC concentration in the car is lower than the relevant standard, and when the mileage is only 4,000 km, the benzene organic matter and the TVOC concentration in the car are clearly exceed limits of relevant standard.

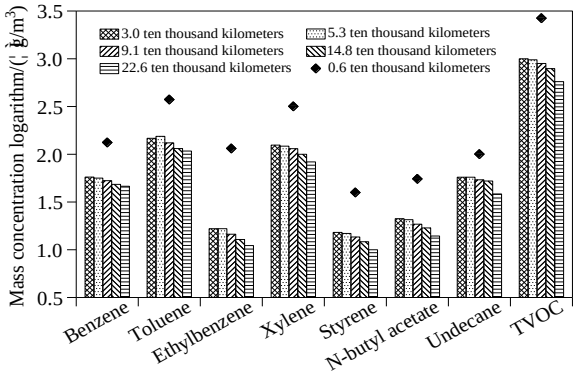

Figure 8: Influence of car mileage on concentration of various VOCs in the car

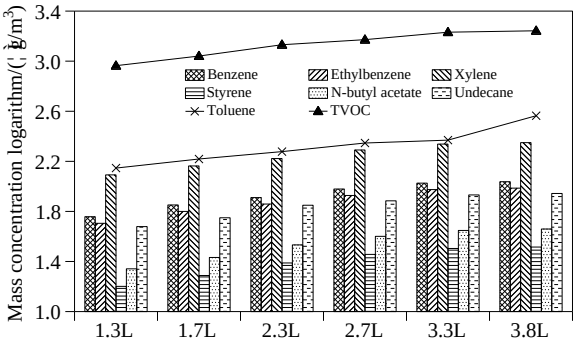

Figure 9: Influence of car displacement on concentration of various VOCs in the car

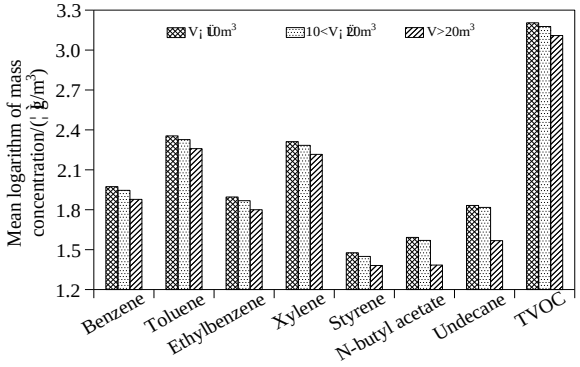

Figure 10: Influence of interior space on concentration of various VOCs in the car

Figure 9 shows the influence of different car displacements on concentration of various VOCs in the car. It can be seen from the figure, as the car exhaust displacements increase, the total amount of VOCs in the car is

also growing. The total internal VOC of cars with a displacement of 3.6L is about 10% higher than that of the cars with a displacement of 1.3L, and for cars with displacement of 3.6L, the in-car toluene and xylene concentrations also seriously exceed the standard. For cars with a displacement of 1.3L, the concentration of benzene organic matter in the car is significantly lower than the specified standard value. The larger the exhaust displacements of the car, the more harmful VOCs are emitted, and the harmful VOCs are more likely to penetrate into the interior of the car.

Figure 10 shows the influence of the car interior space on the concentration of various VOCs. It can be seen from the figure that when the space inside the vehicle is small ($V<10m^3$), the typical VOC concentrations of toluene, ethylbenzene and styrene are 231.8μg/m^3, 82.9μg/m^3 and 27.7μg/m^3, respectively; when the space inside the vehicle is large ($V>20$ m^3), the concentrations of above VOCs are 178.6μg/m^3, 61.3μg/m^3, and 19.9μg/m^3, respectively, which are about 22.9%, 26.1%, and 28.2% lower than those of cars with $V<10m^3$. It shows that the larger the space inside the car, the lower the concentration of harmful VOCs, but the reduction extent is relatively flat.

The smaller the space inside the car is, the less air is circulated, and the VOCs generated by the decorative materials cannot be discharged quickly. Therefore, the concentration of VOCs accumulated in the car is larger. The statistical results show that the content of benzene organic matter is basically exceeding the standard when the space inside the vehicle is $V<10m^3$. When the interior space is $V>20m^3$, only the xylene content exceeded the standard.

4. Conclusion

From the two aspects of external environmental factors and vehicle factors, this paper studies the influence of in-car temperature, humidity, vehicle type, vehicle mileage, vehicle exhaust displacement and other factors on the harmful volatile organic compounds (VOC) in the automobiles. The research conclusions are as follows:

(1) In terms of external environmental factors, the increase of temperature and relative humidity in the car will cause the VOC concentration in the car to increase, and the influence of temperature on the VOC concentration in the car is more significant; being in area with poor environment and serious exhaust emissions for a long time will increase the VOC concentration in the car; when the natural wind speed increases, the concentration of VOC pollutants in the car gradually decreases.

(2) In terms of vehicle factors, the VOC concentration in high-end cars is significantly higher than that in low-end cars, and the VOC concentration of new cars is higher than that of old cars. As the car age and mileage increase, the VOC concentration in the car begins to decrease. The car exhaust displacement is proportional to the VOC concentration in the car, and the interior space is inversely proportional to the VOC concentration. The influence of the change in the interior space on the harmful VOC concentration is relatively small.

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