FUNDAMENTAL STUDY ON PARTICLES, ULTRA-FINE PARTICLES AND OZONE IN THE CAR COMPARTMENT

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ABSTRACT

The concentrations of ozone, particles (PM\(_{10}\) and PM\(_{2.5}\)) and ultra-fine particles were measured during driving the automobile and during standing. Two ventilation modes were prepared; 1) all fresh air mode and 2) all re-circulation mode. The windows of the automobile had been always closed during this measurement. The indoor/outdoor ratio of the concentrations and the correlation among those substances were reported. The concentrations of particles (PM\(_{10}\) and PM\(_{2.5}\)) and ultra-fine particles were dramatically had been increased while the automobile followed the trailer bus. The average indoor/outdoor ratio of ozone during all fresh air mode was higher than that during all re-circulation mode. The correlation coefficient between indoor ozone concentration during all fresh air mode and that during all re-circulation mode was fairly high at 0.63. There were no significant correlation between indoor/outdoor ratio of particles and that of ozone. The ozone deposition velocity in the car compartment was calculated to be 3 m/h by using the measured air-change rate and indoor/outdoor ratio of ozone.

KEYWORDS

Particle, Ultra-fine particle, Ozone, Car compartment, Indoor/outdoor ratio

INTRODUCTION

The requirement for the indoor environmental quality of automobile might be closed to that for buildings and dwellings. People often spend long time in the automobile during commuting and leisure. Therefore indoor environment in car compartment could be regarded as a kind of residential environment equipped with HVAC system. The notable characteristics of the car compartment are, e.g., sensitiveness by the outdoor environment and clear functionality for driving performance. The purpose of this study was to know influence of outdoor environment on indoor environment of automobile. This paper presents investigation on the indoor air quality of car compartment during driving automobile and standing. Especially particles (PM\(_{2.5}\) and PM\(_{10}\)), ultra-fine particles and ozone which were induced to inside from outdoors, were focused on in this study.

EXPERIMENTAL METHODS

Test using stood automobile

Test with stood automobile was conducted using a compact automobile, which was stopped in the campus of Musashi Institute of Technology with engine operated. This test had been conducted between March to December, 2006. The experimental automobile is a compact automobile with a compartment volume of 3m\(^3\). The experimental automobile is a 1.38 liter displacement car. Seating capacity is 5 persons. The number of people occupied the car compartment was between 2 and 4. The

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indoor temperature was kept at 22°C by the air-conditioner and the supply air flow of air-conditioner outlet was 3.8m³/min. Two ventilation modes were prepared; 1) all fresh air mode, i.e., with no re-circulation, and 2) all re-circulation mode, i.e., with no outside air intake except infiltration. The supply air outlet was located in front of the driver. The measured items and instruments are given in Table 1.

<table>
<thead>
<tr>
<th>Measured items</th>
<th>Instruments</th>
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<tbody>
<tr>
<td>CO₂</td>
<td>Multi-Gas Monitor Innova</td>
</tr>
<tr>
<td>Ozone</td>
<td>Ozone monitor Dylec</td>
</tr>
<tr>
<td>Particles(PM₂·₅・PM₁₀)</td>
<td>DUST Trak (TSI)</td>
</tr>
<tr>
<td>Ultra-fine particles</td>
<td>P-Trak (TSI)</td>
</tr>
</tbody>
</table>

Test using driven automobile
Test with driven automobile was conducted using the experimental automobile on the road. This test had been conducted in March, June, August 2006 and January 2007. The number of people occupied the car compartment was 3 in this test. The set up of indoor environmental factors was the same as the test using stood automobile. The main driving course for the test using driven automobile was from the campus of Musashi Institute of technology (Setagaya, Tokyo) to suburbs, e.g., Mt. Fuji area (Yamanashi), and Miura peninsula (Kanagawa). In this driving course, tunnels, highways, traffic roads, mountain roads were included.

RESULTS
The indoor concentrations of PM₂·₅ and ultra-fine particles as a function of time on August 3rd, 2006 are drawn in Figure 1. This figure includes the data when the experimental automobile followed the trailer bus exhausted dirty smoke on the mountain road toward Mt. Fuji. The PM₂·₅ concentration during the period while following the trailer bus was higher than 1000 µg/m³ and the ultra-fine particles concentration during the above period was extremely high. Although this situation was occurred by the experimental procedure, people occupied the automobile could avoid such a extremely high concentrations by changing to all re-circulation mode in real case. The PM₂·₅ concentration except the above period was not categorized to the unhealthy level in EPA’s Guidelines for the Reporting of Daily Air Quality.

![Figure 1. The indoor concentrations of PM₂·₅ and ultra-fine particles as a function of time on August 3rd, 2006](image)
The indoor/outdoor ratio of the substances

The indoor/outdoor (I/O) ratio of the concentrations of particles (PM$_{10}$ and PM$_{2.5}$), ultra-fine particles and ozone for the test using stood automobile are shown in Figure 2. Those for the test using driven automobile are shown in Figure 3. It was found that I/O ratios of particles, ultra fine particles, and ozone during all fresh air mode were higher than those during all re-circulation mode both for the test using stood automobile and driven automobile.

![Figure 2. The indoor/outdoor ratio during standing](image)

![Figure 3. The indoor/outdoor ratio during driving](image)

The correlation coefficient between indoor ozone and outdoor ozone

Figure 4 shows the correlation between indoor ozone concentration and outdoor ozone concentration during all fresh air mode. Figure 5 shows that during all re-circulation mode. The correlation coefficient between indoor ozone concentration and outdoor ozone concentration during all fresh air mode was fairly high at 0.63. On the other hand, that during all re-circulation mode was low at 0.35.

![Figure 4. Correlation between indoor ozone and outdoor ozone during fresh air mode](image)

![Figure 5. Correlation between indoor ozone and outdoor ozone during all re-circulation mode](image)

DISCUSSION

In Figure 4, the correlation coefficient between indoor ozone concentration and outdoor ozone concentration during all fresh air mode was fairly high. On the other hand, Figure 5 shows that the correlation coefficient between those during all re-circulation mode was low. During all fresh air mode, chemical reaction time between ozone and VOCs was not so long that the decrease in ozone concentration by chemical consumption would not be significant. During all re-circulation mode, both chemical reaction and ozone deposition would play an important role in the car compartment, because the age of air was long. While the ozone decrease was mainly controlled by the chemical reaction during all fresh air mode, ozone decrease could be considerably controlled by both chemical reaction
and deposition during all re-circulation mode. Therefore the correlation between indoor ozone and outdoor ozone during all re-circulation mode might be low.

Weschler explained the relationship between ozone deposition velocity and the indoor/outdoor ratio of the ozone concentrations when the room does not have outbreak of remarkable reaction VOC and ventilation as follows:\(^2\):

\[
\frac{I}{O} = \frac{N}{N + k \frac{A}{V}} \quad (\text{l})
\]

where:

\(N\): Air change rate of the car compartment \((\text{1/h})\)
\(A\): Surface area in a compartment \((\text{m}^2)\)
\(V\): Volume of the compartment \((\text{m}^3)\)
\(k\): Ozone deposition speed to the room surface \((\text{m/h})\)

For solving equation (1), the value of air change rate, \(N\), was needed. The air change rate calculated by the CO\(_2\) concentration in the car compartment was shown in Table 2. The calculated ozone deposition velocity, \(k\), was presented in Table 3.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Air change rate</th>
<th>Table 3</th>
<th>Calculated value of k</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All fresh air mode</td>
<td>All re-circulation mode</td>
<td>Average ± Standard deviation</td>
</tr>
<tr>
<td>Test using driven automobile</td>
<td>43.1</td>
<td>3.7</td>
<td>Ozone (ppb)</td>
</tr>
<tr>
<td>Test using stood automobile</td>
<td>42.2</td>
<td>4.2</td>
<td>All fresh air mode</td>
</tr>
<tr>
<td></td>
<td>All re-circulation mode</td>
<td></td>
<td>All re-circulation mode</td>
</tr>
</tbody>
</table>

The calculated ozone deposition speed during all fresh air mode is identical to that during all re-circulation mode. This ozone deposition rate, which is expressed with “\(k \times \frac{A}{V}\)”, is greater than the air change rate during all re-circulation mode.

**CONCLUSION**

The indoor air quality was measured during driving and standing in the car compartment. Especially particles (PM\(_{2.5}\) and PM\(_{10}\)), ultra-fine particles and ozone were focused on in this study. The correlation coefficient between indoor ozone concentration and outdoor ozone concentration during all fresh air mode was fairly high. On the other hand, that during all re-circulation mode was low. The calculated ozone deposition speed during all re-circulation mode was greater than the air change rate during the above period. The ozone deposition would play an important role especially during all re-circulation mode.

**ACKNOWLEDGMENTS**

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**REFERENCES**

1) U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Guideline for Reporting of Daily Air Quality – Air Quality Index (AQI), EPA-454/B-06-001, May 2006