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SCREENING TECHNIQUE FOR SPECIFYING ROADS WITH HIGH CONCENTRATIONS
BY USING REGRESSION EQUATIONS

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Abstract: In order to estimate benzene concentrations and benzo[a]pyrene concentrations at the roadsides and in the crossroads in Osaka City, the emission factors of benzene of benzo[a]pyrene for gasoline cars and for diesel cars were measured by using the portable sampling equipment collecting directly exhaust gas. The regression equations to calculate the concentrations at the roadsides and at the crossroads were induced as the functions of building height, of road width, and of wind speed from CFD simulations. The concentrations estimated showed that there were some locations with the high concentrations exceeding the atmospheric environmental standard in Japan. Such screening technique is useful because the assessment is easy.

Key words: benzene, benzo[a]pyrene, emission factors, screening technique, regression equation.

INTRODUCTION
The exhaust gas emitted from cars is one of the main causes of air pollutions. The exhausts gas abundantly includes hazardous substances; nitrogen oxide, sulphur oxide, carbon monoxide, suspended particle matter, BTEX (benzene, toluene, ethyl benzene, and xylene), and PAHs (Polycyclic Aromatic Hydrocarbons). Both benzene and benzo[a]pyrene, which is one substance of PAHs, are classified with Group 1 (The agent is carcinogenic to humans) by IARC (International Agency for Research on Cancer) (http://www.epa.gov/ncea/iris/index.html). Research on emissions of these substances from cars has been carried out worldwide. The limited monitoring network of air pollutions cannot perfectly cover all of the locations with the high concentration. In order to conserve the air quality, it is necessary to know easily where some locations with high concentration are. In this study, the regression equations to estimate the concentration in the roadsides and in the crossroads were induced from CFD (Computational Fluid Dynamics) simulations by varying the parameters of building height, road width, wind speed and wind direction. Finally using the emission factors obtained from the portable sampling equipment, the regression equations, and the traffic volume, benzene concentration and benzo[a]pyrene concentration at the roadsides and at the crossroads in Osaka City were calculated.

MEASUREMENT OF EMISSION FACTOR

Sampling equipment
The outline of the portable sampling equipment (Shi, 2009) is shown in Figure 1. The sampling head is inserted into the muffler of a car and is fixed. The exhaust gas is sampled at the constant flow rate by a pump installed into the car and is collected by the absorber. The absorbers used are TenaxTA60/80 for collecting BTEX and TenaxTA20/35 for collecting PAHs. Each substance is analyzed by GC-MS (Simazu-QP2010) with Thermal Desorbor (Perkin Elmer- Turbo Matrix ATD). The emission factor $EF$ [$\text{gkm}^{-1}$] of each substance is determined by equation (1).

$$c = \frac{m}{Q}, \quad EF = \frac{cVQt}{2L}$$

Where $c$ is a substance concentration into exhaust gas [$\text{gcm}^{-3}$], $m$ is a substance weight into sampling tube [$\text{g}$], $Q$ is a sampling volume [$\text{m}^3$], $V$ is a displacement volume [$\text{m}^3$], $\Omega$ is number of rotations [$\text{min}^{-1}$], $t$ is sampling time [$\text{min}$], and $L$ is a mileage [$\text{km}$].

Emission factor of benzene
The samplings from 30 gasoline cars for BTEX were carried out from November to December 2007 (Shi, 2009). The emission factor of new cars drastically decreased due to the regulation of hydro carbon emissions. It is well known that gasoline cars emit plenty of hydro carbon emissions in cold start. Assuming to be cold start until the mileage of 4km,
emission factor in hot start was estimated. The relation between emission factor in hot start and manufacture year is shown in Figure 2. Considering the use rate according to manufacture year and the mixing rate of cold start cars, emission factors according to year were estimated and are shown in Figure 3. Assuming to be the mixing rate of 2%, benzene emission factor in 2007 was 4.5mgkm\(^{-1}\).

The samplings from 5 diesel cars for BTEX were carried out from June to August 2009. The emission factor of diesel cars was hardly changed in cold start. Osaka City (the target area) has the regulation that diesel cars which do not satisfy hydro carbon emission standard can not enter into Osaka City. Therefore the average emission factor of 5 diesel cars was used to estimate benzene concentration. Benzene emission factor for diesel cars is shown in Table 1.

Table 1. Emission factor for diesel cars

<table>
<thead>
<tr>
<th>Car No.</th>
<th>Manufacture year</th>
<th>Benzene emission factor[mg/km(^{-1})]</th>
<th>Benzo[a]pyrene emission factor[ng/km(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2001</td>
<td>3.27</td>
<td>5245</td>
</tr>
<tr>
<td>2</td>
<td>2004</td>
<td>2.39</td>
<td>331</td>
</tr>
<tr>
<td>3</td>
<td>2005</td>
<td>0.122</td>
<td>139</td>
</tr>
<tr>
<td>4</td>
<td>2007</td>
<td>0.082</td>
<td>281</td>
</tr>
<tr>
<td>5</td>
<td>2008</td>
<td>0.029</td>
<td>42</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1.18</td>
<td>1200</td>
</tr>
</tbody>
</table>

Emission factor of benzo[a]pyrene

The samplings from 3 gasoline cars for PAHs were carried out on October and on November 2009. The annual decrease rate of benzo[a]pyrene emission factor was assumed to be the same as the annual decrease rate of benzene emission factor. Based on this assumption, benzo[a]pyrene emission factor in 2007 of 570ngkm\(^{-1}\) was determined. Benzo[a]pyrene emission factor for gasoline car is shown in Table 2.

The same diesel cars were used to sample PAHs. Based on the same method to estimate benzene emission factor, benzo[a]pyrene emission factor was determined. Benzo[a]pyrene emission factor for diesel cars is shown in Table 1.

Converting to benzo[a]pyrene from TEF(Toxicity Equivalent Factor) of PAHs, benzo[a]pyrene_TEQ emission factor was 660ngkm\(^{-1}\) for gasoline car and 1700ngkm\(^{-1}\) for diesel car, respectively.

Table 2. Benzo[a]pyrene emission factor for gasoline cars

<table>
<thead>
<tr>
<th>Car No.</th>
<th>Manufacture year</th>
<th>Emission factor[ng/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2003</td>
<td>27.1</td>
</tr>
<tr>
<td>2</td>
<td>2006</td>
<td>49.7</td>
</tr>
<tr>
<td>3</td>
<td>2008</td>
<td>5.7</td>
</tr>
</tbody>
</table>

NUMERICAL SIMULATION MODEL

CFD used in this study is Flow Designer (Advanced Knowledge Limited.). The turbulent model is k-\(\varepsilon\), and the solution method is SIMPLE.
Simulation of crossroads

The crossroads model simplified (Shi, 2006) is shown in Figure 4. Road width is D[m], and building height is H[m], and pavement width is 3m. Wind direction is south, and wind speed is U[ms$^{-1}$]. The east-west lateral boundary condition is symmetry. Emission from exhaust gas is uniformly given from ground level to 2m on road. The evaluation region is the range of 20m in crossroads at the height of 1.5m on pavement. The average concentration in the evaluation region is the evaluation concentration. The average concentrations were calculated by all combinations of H=3, 4, 5, 6, 7, 8, 9, 12, 15, 18, 21, 24m, and of D=8, 12, 18m, and of U=1, 2, 3, 4ms$^{-1}$. The average concentrations for the change of H are shown in Figure 5. The average concentrations increased until the building height of 5m, and decreased over the building height of 5m. Therefore the two regression equations induced by these simulations were

$$C = 0.75U^{-0.91}D^{-0.27}H^{0.67} \quad 3 \leq H \leq 5 \quad (2)$$

$$C = 4.29U^{-0.94}D^{0.16}H^{-0.92} \quad 5 \leq H \quad (3)$$

The same simulations were carried out for the crossroads model with high-level roads. The average concentrations in most simulations were lower than without high-level roads.

Simulation of roadsides

The roadsides model simplified is shown in Figure 6. The simulations were carried out by all combinations of RH(building height on right side) = LH (building height on left side)=0-48m on the same conditions of D=18m, and of wind direction of west, and of U=1ms$^{-1}$. The evaluation region is the range of the distance from buildings of 0.5m at the height of 1.5m. The average concentration in the evaluation region is the evaluation concentration. The average concentrations for the change of H are shown in Figure 7. The average concentrations were irregularly varied by the change of the building height. The vertical flows at H=8, 10, 16, 28, 38m are shown in Figure 8. Up to the building height of 8m, the inflow into the street canyon from the above of the building height was prevented so that the wind speed at the ground level decreased and the concentration increased. Up to the building height of 18m, one clear vortex was formed in the street canyon. The wind speed at the ground level increased and the concentration decreased accompanying the increase of the building height. Up to the building height of 32m, two vortexes were formed in the street canyon. Over the building height of 32m, the clear vortex was not found in the street canyon. The inflow from the lateral sides was dominant. As the characteristic of the flow was unpredictably changed due to the building height, the regression equation was not induced. Therefore the simulations were carried out by all combinations of 5 types of RH (building height on right side, 0-48m), and of 5 types of LH (building height on left side, 0-48m), and of D=12, 18, 24, 36m, and of 2 types of wind direction of west and of north. The calculation result was used as the database.

SCREENING RESULTS

Benzene concentrations and benzo[a]pyrene concentrations at the roadsides of 6999 and at the crossroads of 449 in Osaka City were calculated by using the traffic volume, the emission factor, and the regression equations or the database. Benzo[a]pyrene concentrations at the crossroads and at the roadsides are shown in Figure 9 and in Figure 10, respectively. Though the results of benzene concentrations were not presented here, the distributions of concentrations were the same as Figure 9 and Figure 10. The unit risk of benzo[a]pyrene and of benzene are 9×10$^{-10}$ per gm$^{-3}$ and 5×10$^{-10}$ per gm$^{-3}$, respectively. Setting the screening level to 10$^{-8}$ per gm$^{-3}$ and 5×10$^{-7}$ per gm$^{-3}$, respectively, Atmospheric environmental standard of benzene is 3gm$^{-3}$ but atmospheric environmental standard of benzo[a]pyrene is not regulated, yet. According to the calculations at the roadsides, benzene concentration at a few locations exceeded atmospheric environmental standard but benzo[a]pyrene concentration at most locations exceeded 0.11ngm$^{-3}$. According to the calculations at the crossroads, the average benzene concentration and the average benzo[a]pyrene concentration were 2.2µgm$^{-3}$ and 0.56ngm$^{-3}$, respectively. These results suggested that atmospheric environmental standard of benzo[a]pyrene should be regulated as soon as possible.

CONCLUSIONS

In order to estimate benzene concentrations and benzo[a]pyrene concentrations at the roadsides and in the crossroads in Osaka City, the emission factors of benzene of benzo[a]pyrene for gasoline cars and for diesel cars were measured by using the portable sampling equipment collecting directly exhaust gas. The regression equations to calculate the concentrations at the roadsides and at the crossroads were induced as the functions of building height, of road width, and of wind speed from CFD simulations. The concentrations estimated showed that there were some locations with high concentrations exceeding...
the atmospheric environmental standard in Japan. The simulations in detail and the measurements to verify the cause of the high concentrations will be performed.

Figure 8. The vertical flows at H=8, 10, 16, 28, 38m.

Figure 9. Benzo[a]pyrene concentrations at the roadsides.

Figure 10. Benzo[a]pyrene concentrations at the crossroads.
REFERENCES
http://www.epa.gov/ncea/iris/index.html