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# Volatile Organic Compound Levels inside Vehicles using Commercial Air Cleaning Devices

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Vehicle occupant exposure to volatile organic compounds (VOCs) has been a subject of concern in recent years because of higher levels of VOCs inside vehicles as compared to the surrounding ambient atmosphere and because of the toxicity of VOCs. The effectiveness of two commercial ACDs for the removal of selected VOCs in the interior of automobiles was evaluated on 115 commutes through urban (Taegu) commutes by two cars and 9 idles. The idling and commuting studies conducted under four different driving conditions showed that the two commercial ACDs were not effective for the removal of VOCs in the interior of vehicles. The concentrations of all target VOCs except benzene were significantly higher ($p<0.05$) in the interior of older car than of newer car. The mean levels of benzene and toluene measured in this study were well excess of earlier other studies in the United States, besides Los Angeles with which was comparable. It was reported that the in-vehicle exposure to benzene and corresponding upper-bound cancer risk were about 8 times higher than those for outdoor environment, while they were about half of those from indoor environment.

Key words : in-vehicle, VOCs, ACDs, commute, exposure, risk, outdoor, indoor

## 1. Introduction

Many volatile organic compounds (VOCs) have been found at the elevated levels in the interior of motor vehicles as compared to the levels in the other microenvironments in which gasoline is not used. The elevated levels of VOCs result from the penetration of VOCs in vehicle exhaust and evaporated gasoline into vehicles (Weisel et al., 1992). Wallace (1988) reported that personal exposure to several VOCs such as benzene, m-/p-xylene, and ethylbenzene was strongly associated with vehicle use. Jo and Choi (1996) indicated that motor vehicle exhaust and evaporative emissions were major sources of both auto and bus occupants exposures to aromatic VOCs in both urban and suburban commute segments in Korea. Other recent studies (Chan et al., 1991a; Chan et al., 1991b; SCAQM, 1989; Weisel et al., 1992) found that in-vehicle concentrations of gasoline-derived VOCs were upto 8 times higher than the corresponding ambient air nearby monitoring sites. Highest in-vehicle VOC concentrations were found during high traffic density periods in the morning and evening rush hours (Chan et al., 1991a).

The use of air cleaning devices (ACDs) equipped with activated carbon filter in the interior of vehicles is expected to reduce the vehicle occupants exposure to VOCs. Granular activated carbon (GAC) has

been applied for many years to control industrial and indoor gaseous contaminants (VanOsdell et al., 1996; Nelson and Harder, 1974; Nelson and Harder, 1976; Nelson et al., 1976).In Korea, even though the significance of VOC exposure for public health risks during traveling on vehicles has not previously been appreciated, several commercial ACDs has been employed in some autos in order to remove an offensive odor and/or particulate matters from vehicle cabin air. Since the ACDs designed to reduce the offensive odor include activated charcoal trap, they are also expected to reduce non-odorous VOC levels in vehicle cabins. Present study evaluated the effectiveness of two commercial ACDs for the removal of six target VOCs in the interior of automobiles during idling and while commuting along an urban (Taegu) route. In addition, the cancer risk from the in-vehicle exposure to benzene was estimated and compared with that from the exposure to indoor and outdoor air benzene.

## 2. Experimental Methods

### 2.1 Commuting Route

Two criteria were established for the selection of the commute route as follows: (1) to pass through downtown Taegu, and (2) to include one of the major lines for commuters in Taegu. The commuting route was a 10-lane main roadway passed through downtown Taegu and covered 4.3 km of eastern route, 4.0 km of central downtown route, and 3.2 km of western route, with a total distance of 11.5 km. Along this route, there were 20 signalized intersections. The morning commutes originated from the eastern route and the evening commuting route was the morning commuting route in reverse. The vehicle speeds for the morning commutes ranged from 9.3 to 19.7 kph, with a mean speed of 12.4 kph, while for the evening commutes they ranged from 10.6 to 16.8 kph, with a mean speed of 12.6 kph.

### 2.2 Study Protocol

This study measured concentrations of six aromatic VOC (benzene, toluene, ethylbemzene, o-xylene, m-xylene, and p-xylene) in the passengers side and the back seat of two autos on 115 commute trips and 9 idles. Ambient air concentrations were also measured for the idle study. The parameter controlled for the entire experiments includes vehicles tested, fuel type, ventilation condition, interior fan speed and blower direction, and location of ACD in cabin. The two automobiles were chosen to represent newer (less kilometer) and older vehicles. They were a 1995 Hyundai Sonata II four-door sedans with 23,125 km and a 1991 Hyundai Elantra four-door sedans with 86,234 km. The two automobiles were employed for the commuting study, while the newer one only was employed for the idling study. The malfunctions of the fuel, engine, and exhaust systems were not indicated by either the test car during the entire experiment. Fuel from a single company (Ssangyong Korean Petroleum Company) was used to avoid any confounding factors that might influence the concentrations of target compounds due to different fuel constitutions. The entire experiments were performed with the windows and vents closed to represent low ventilation condition. The interior fan was turned on medium speed with the blower direction set to the up-down position and the temperature level set to the personal comfort level of the drivers. The ACDs were placed in the middle of the flat board behind the back seat, the typical ACD location for Korean autos.

Two most expensive commercial ACDs for autos in Korea were employed for this study. The two ACDs equipped with activated carbon filter, denoted ACD-1 and ACD-2, were purchased from local retailer (retail price: $ 120 and $135, respectively). The filters for ACD-1 and ACD-2 consist of fiber filter media with dimensions 4 x 23 x 3.5 cm and 15 x 23 x 0.6 cm, respectively. According to the ACD manufacturers, the flow rates of the ACD-1 and ACD-2 ranged from 30 to 60 $m^3/h$ and from 10 to 35 $m^3/h$, respectively. The pore sizes of the ACD-1 and ACD-2 were about 1 and 2 mm, respectively, so that an object could easily be seen through the pores. Each ACD was new when tested, and its filters were not preconditioned prior to the study. The two ACDs were employed for the idling study, while ACD-2 only was employed for the commuting study.

2.3 Test of ACDs While Idling

Two commercial ACDs (ACD-1 and ACD-2) were tested for the removal efficiency of target VOCs in the passenger's side and the back seat of Car A (Sonata II) while idling. The idling study included two driving conditions: no use of ACDs with turned interior fan off and use of ACDs with turned interior fan off. This test was performed by simultaneously measuring the in-auto and vehicle exterior air concentrations during idling, with or without an ACD in the cabin. Car A was parked in an outdoor stadium of Kyungpook National University, in which was located approximately 1 km away from the local road, to minimize any confounding factors from local traffic. The car was positioned so that the exhaust blew away from it, to minimize the possibility of the exhaust penetrating the interiors. Prior to the idling experiments, the windows of the car were left open for a minimum of two hours to eliminate any residual levels in the interior of the automobiles and to allow the engines to return to the ambient temperature. The windows were then closed and a 30 min in-vehicle air sample was collected prior to starting the engine. A corresponding 30 min vehicle exterior air sample was collected at 20 m upwind of the automobile. The engine was started, and three consecutive 30 min idle samples were collected. If the ACD was used, ACD-1 or ACD-2 was turned on during the third 30 min idling only. This whole procedure was repeated three times for each driving condition.

2.4 Test of an ACD While commuting

The ACD-2 only was tested for the removal efficiency of target VOCs inside vehicle while commuting along an urban route during winter of 1996. Winter season was selected because high emissions from motor vehicles can be associated with cold ambient temperature (Bruetsch, 1981).The commuting study included four driving conditions: no use of ACDs with turned interior fan off; use of ACDs with turned interior fan off; use of ACDs with turned interior fan on; and no use of ACDs with turned interior fan on. The commutes were conducted during the morning (7:00-9:00) and the evening (5:30-7:30) rush hours on standard workdays (Monday through Friday).The removal efficiency was determined by measuring VOC concentrations in the passenger's side and the back seat of two cars with or without ACD. Two cars were driven in tandem, positioning in reverse for the morning and the evening commutes. For the morning or evening commute, two autos from the origin simultaneously and arrived at the destination at similar times.

One morning commute and one evening commute were done by each automobile in one sampling day, with one cabin sample collected for each commute of each automobile. The ACD was assigned to only one car for one sampling day and to only the other car for the next sampling day.

2.5 Sampling and Analytical Methods

2.5.1 Sampling

Air samples were collected for 6 aromatic VOCs (benzene, toluene, ethylbenzene, o,m,p-xylenes) in the interiors of two automobiles while idling or commuting. Air was drawn, using personal air samplers (AMTEK MG4), through 1/4 in. outside diameter (O.D.) by 4.4 in. long glass tubes packed with Tenax GC adsorbent (about 0.4 grams). The traps were positioned in the breathing zone. For idling studies, flow rates were adjusted to 0.3 L/min for a cabin sample of ACD-operated car which were sampled for 30 minutes for a nominal volume of 9 L, and to 0.1 L/min for a cabin sample of non-ACD-operated car which was sampled for 30 minutes for a nominal volume of 3 L. Air volume collected during the commuting studies ranged from 1. 6 L to 2.5 L for the cabin samples. The sample volume was determined based on the relative expected concentrations for each experimental condition.

2.5.2 Analysis

VOCs trapped on the Tenax GC trap were measured by applying EPA Method TO-1 (Winberry et al., 1988). The major components of the analytical system included a thermal desorption system (Tekmar 6000) and a gas chromatography (GC,Varian STAR 3400CX) with a high resolution capillary column (J&W DB-WAX) and a flame ionization detector. The adsorbent trap was thermally desorbed at 250°C for 10 minutes, and the target VOCs were cryofocussed at -150°C on an internal trap. The internal trap, then, was heated at 200°C and the target VOCs were recryofocussed at -150°C on the Cryofocussing Module System (CMS) mounted onto the GC. The cold CMS was rapidly heated to 200°C and backflushed to transfer to the GC. The initial oven temperature of the GC was set to 35°C for 8 minutes and ramped at 4 °C/min to 200°C. The identification of each compound was confirmed by its retention time. The quantitative analysis of target VOCs was performed by using the calibration curves of the five concentrations for all target external standards.

2.5.3 Quality Control/Quality Assurance

Quality control included laboratory and field blank traps, spiked samples, and duplicate measurements. The performance of the entire analytical system was checked daily by analyzing two blank traps and an external standard. At the beginning of the day, a laboratory blank trap and a field blank trap were analyzed to check trap contamination and an external standard to check the quantitative response. Trap contamination was not recognizable for the entire series of experiments. When the quantitative response differed more than 20% from that predicted by a specified calibration equation, a new calibration equation was determined. Seven sampling traps spiked with 10.5 ng of VOC standards were used to determine the method detection limits (MDLs) of the system. The MDLs ranged from 0.2 to 1.3 $\mu g/m^3$ for the target VOCs.

The precision of the sampling and analytical techniques was determined by calculating the relative range for the com-

pound i($RR_i$) with the following equation:

$RR_i = 100 \times R_i/X_i$

where Ri=the absolute difference in $\mu g/m^3$ between a duplicate measurement (X1) and an average of four segment measurements (X2) for the compound i ($|X1-X2|$), and $X_i$=the average concentration in $\mu g/m^3$ for the compound i ([X1+X2]/2). As shown in Table 1, the mean $RR_i$ for all compounds were less than 20%.

Table 1. Mean Relative Ranges (MRR) for Duplicate In-Vehicle VOC Samples

| | MRR | |
|---|---|---|
| compound | idle | commute |
| benzene | 0.18 | 0.14 |
| toluene | 0.18 | 0.15 |
| ethylbenzene | 0.10 | 0.11 |
| p-xylene | 0.13 | 0.17 |
| m-xylene | 0.16 | 0.18 |
| o-xylene | 0.16 | 0.18 |

## 3. Results and Discussion

### 3.1 Idling Study

The in-vehicle VOC samples were collected in the passenger's side and the back seat of an automobile prior to and during three consecutive idles. Ambient air samples were also collected prior to idles. The in-vehicle VOC concentrations simultaneously measured in the two sampling locations were averaged to represent the in-vehicle levels for a single given sampling period. The mean VOC concentrations obtained from three idle runs for each of three ACD conditions are shown in Table 2A, 2B and 2C for each ACD condition. The concentrations of all target VOCs were elevated in the in-vehicle air samples collected prior to starting the engine as compared to the ambient air samples, indicating that even while the

Table 2. Mean VOC Concentrations ($\mu g/m^3$) ± standard deviation measured in the ambient air, and the interior of and automobile prior to and during 3 consecutive 30 min idles by ACD condition

| compound | prior ambient | prior in-vehi. | 1st-idle | d12[a] (%) | 2nd-idle | d23[b] (%) | 3rd-idle |
|---|---|---|---|---|---|---|---|
| | | | (A) ACD Off | | | | |
| benzene | 4.9+2.3 | 6.6+4.0 | 10.3+3.8 | 14 | 11.9+4.0 | 24 | 15.2+5.3 |
| toluene | 24.4+6.3 | 49.4+15.8 | 65.7+54.7 | 19 | 79.1+36.3 | 19 | 95.3+40.3 |
| ethylbenzene | 1.5+1.2 | 3.1+2.3 | 4.4+2.0 | 40 | 6.6+5.0 | 18 | 7.9+6.8 |
| p-xylene | 1.3+1.7 | 2.4+1.5 | 4.8+2.1 | 25 | 5.3+3.9 | 19 | 6.4+4.5 |
| m-xylene | 0.9+1.3 | 3.4+2.5 | 6.0+2.1 | 40 | 9.0+4.3 | 14 | 10.4+3.7 |
| o-xylene | 2.3+1.6 | 3.4+1.7 | 4.7+2.5 | 32 | 6.5+3.2 | 18 | 7.8+6.8 |
| | | | (B) ACD-1 On During 3rd idle Only | | | | |
| benzene | 3.3+2.1 | 5.4+4.2 | 22.1+7.8 | 14 | 25.3+12.9 | 15 | 29.5+19.9 |
| toluene | 32.5+15.6 | 60.5+37.1 | 69.4+50.1 | 7 | 74.1+41.1 | 14 | 85.5+51.5 |
| ethylbenzene | 2.3+1.3 | 4.6+2.6 | 6.1+3.4 | 13 | 7.2+3.8 | 21 | 8.9+3.3 |
| p-xylene | 1.1+1.6 | 3.7+1.7 | 5.3+2.4 | 2 | 5.4+2.7 | 12 | 6.0+2.7 |
| m-xylene | 1.2+1.2 | 4.3+3.6 | 6.9+4.7 | 57 | 12.4+4.6 | 5 | 13.0+4.3 |
| o-xylene | 4.1+1.6 | 5.3+2.2 | 7.0+2.8 | 6 | 7.4+3.3 | 5 | 7.8+2.5 |
| | | | (C) ACD-2 On During 3rd idle Only | | | | |
| benzene | 4.3+2.0 | 9.4+6.1 | 15.2+5.0 | 11 | 17.0+5.5 | 27 | 22.2+8.9 |
| toluene | 19.3+5.6 | 75.0+45.3 | 78.7+50.8 | 2 | 80.4+45.2 | 6 | 85.1+49.3 |
| ethylbenzene | 4.5+1.3 | 5.3+2.4 | 7.1+2.3 | 23 | 9.0+4.6 | 38 | 13.3+5.1 |
| p-xylene | 2.4+0.7 | 3.1+1.5 | 3.4+1.2 | 28 | 4.5+2.2 | 22 | 5.6+2.0 |
| m-xylene | 2.6+1.6 | 6.9+3.7 | 8.4+3.6 | 17 | 10.0+5.2 | 10 | 11.1+5.6 |
| o-xylene | 4.7+1.4 | 4.7+1.7 | 5.6+1.8 | 19 | 6.8+3.7 | 12 | 7.7+3.3 |

[a] d12 was obtained by calculating the difference between 1st-idle and 2nd-idle divided by the average of the 1st-idle and 2nd-idle. [b] d23 was obtained by calculating the difference between 2nd-idle and 3rd-idle divided by the average of the 2nd-idle and 3rd-idle.

vehicle was not idling the measured components evaporate from the fuel tank and engine, and penetrate into the interior of vehicles. The in-vehicle concentrations of all target compounds were slightly higher in air samples collected during 1st 30 min idles as compared to air samples collected for 30 minutes prior to starting the engine. One explanation is that more of the compounds evaporate from the hot engine while idling. Furthermore, the in-vehicle concentrations of all target VOCs increased gradually for three consecutive idles for all ACD conditions, indicating that the VOCs accumulates in the cabin as idling time increases. The difference between 1st idle and 2nd idle ranged from 2 to 57% for all target compounds.

The difference between 2nd idle and 3rd idle ranged from 14 to 24% for all target compounds when the ACD was turned off (Table 2A), and ranged from 5 to 21% and from 6 to 38% when the ACD-1 and ACD-2 were turned on (Tables 2B & 2C), respectively. The in-vehicle concentrations of all target compounds were higher in the 3rd idle when ACDs were turned on than in the 2nd idle when ACDs were turned off, while similar results were also observed even when ACDs were not used both in the 2nd idle and 3rd idle. This indicates that the ACDs are not effective for the removal of VOCs in the interior of vehicles.

3.2 Commuting Study

Table 3 summarizes that mean VOC concentrations obtained in two interior locations of two automobiles while traveling along an urban route under 4 different commute conditions with the windows and vent always kept closed. If one of two samples collected in the two interior locations for a single commute was not available due to sampling or analytical problems, it was not included for the comparisons. Similar to the idle study, the in-vehicle VOC concentrations simultaneously measured in the two locations were averaged to represent the in-vehicle levels for a single given sampling period. When the interior fan was turned off, the concentrations of all target VOCs were not significantly different between the two conditions, ACD on and off. Similar results were obtained when the interior fan was turned off. This result is consistent even when the interior fan condition is not considered (Table 4). Hence, with the results of idle study, it is indicated that the ACDs were not effective for the removal of VOCs in the interior of vehicles, suggesting efforts to develop efficient ACDs for VOC removals in order to decrease the in-vehicle exposure to gasoline-derived VOCs. Even though this study did not try to examine the parameters that could influence the effectiveness of ACDs, an observation of this study is that the pore sizes of the ACD filters were so large that an object could easi-

Table 3. Mean Concentrations ($\mu g / m^3$) ± standard deviation measured while commuting, by ACD and interior fan conditions

| compound | ACD off & fan off (n=28) | ACD on & fan off (n=24) | ACD off & fan on (n=32) | ACD on & fan on (n=31) |
|---|---|---|---|---|
| benzene | 63.1+31.5 | 72.7+53.4 | 28.3+8.7 | 35.0+15.5 |
| toluene | 131.8+76.8 | 128.2+55.0 | 101.6+42.7 | 111.4+54.3 |
| ethylbenzene | 11.3+5.5 | 9.6+3.9 | 12.3+7.5 | 13.2+14.2 |
| p-xylene | 8.3+4.0 | 7.3+3.8 | 10.8+6.6 | 12.4+15.8 |
| m-xylene | 20.1+9.6 | 18.3+8.7 | 22.4+15.2 | 21.4+17.9 |
| o-xylene | 11.2+5.4 | 10.5+5.7 | 13.8+9.0 | 14.9+14.1 |

Table 4. In-vehicle VOC Concentrations ($\mu g / m^3$) by the ACD Condition

| compound | ACD off (n=60) Mean | SD | ACD on (n=55) Mean | SD |
|---|---|---|---|---|
| benzene | 46.2 | 29.6 | 52.2 | 41.5 |
| toluene | 113.5 | 60.3 | 117.6 | 52.3 |
| ethylbenzene | 11.8 | 6.3 | 11.6 | 10.9 |
| p-xylene | 9.9 | 5.8 | 10.4 | 12.7 |
| m-xylene | 21.1 | 12.4 | 19.8 | 14.0 |
| o-xylene | 13.1 | 8.1 | 13.3 | 11.8 |

ly be seen through the pores (1 and 2 mm for ACD-1 and ACD-2, respectively), suspecting the filters effectiveness for removing VOCs.

3.3 Comparison of Two Cars

A newer car and a older car were compared for the in-vehicle concentrations averaged the passengers side and the back seat concentrations. The concentrations of all target VOCs except benzene were significantly higher ($p<0.05$) in the interior of older car (Elantra) than of newer car (Sonata II) (Table 5) while commuting along an urban route. These concentration differences may be partially explained by the difference of driving habit of drivers of the two vehicles, such as the habit of keeping inter-vehicle distance while running or idling at traffic lights and/or by the difference of the impact of surrounding vehicles during travels or idling at traffic lights on the interior concentrations of each car. This is supported by that the corresponding roadway concentration differences of two cars were consistent with the difference of the in-vehicle concentrations between two cars. Another possible parameter that caused the concentration differences includes the differences of vehicles intake mechanism and /or differences in wear and tear between the cars.

3.4 In-Vehicle Levels vs Other Studies

Several studies abroad have measured in-vehicle VOC concentrations for automobile travellers. The concentrations of selected in-vehicle aromatic VOCs measured in this and the earlier studies abroad are listed in Table 6. The mean concentrations of benzene and toluene in the present study were comparable with those in Los Angeles, while they were well excess of earlier other studies. On the other hand, the mean concentrations of m&p-xylene and o-xylene in the present study were comparable with those in New Jersey and Raleigh. These differences may be regional, as fuel composition, traffic pat-

Table 5. Comparison of VOC Concentrations ($\mu g / m^3$) between two moving cars

| compound | Sonata II (n=55) Mean | SD | Elantra (n=60) Mean | SD |
|---|---|---|---|---|
| benzene* | 49.0 | 42.5 | 49.1 | 28.6 |
| toluene* | 100.4 | 38.7 | 129.3 | 66.1 |
| ethylbenzene | 9.4 | 3.7 | 13.8 | 11.2 |
| p-xylene | 6.7 | 2.5 | 13.3 | 12.4 |
| m-xylene | 14.1 | 4.8 | 26.3 | 15.6 |
| o-xylene | 8.6 | 5.3 | 17.4 | 12.1 |

*indicates a significant difference between roadway air and in-vehicle air for both autos at $p<0.05$.

Table 6. Mean in-vehicle VOC Concentrations ($\mu g / m^3$) for the present and previous urban studies

| compound | Boston 1989[a] | Raleigh 1999[b] | Los Angeles 1987[c] | 1988[c] | New Jersey 1991[d] | Taegu 1996[e] |
|---|---|---|---|---|---|---|
| benzene | 17.0 | 13.6 | 31.2 | 50.4 | 20.6 | 49.2 |
| toluene | 33.3 | 45.7 | 107 | 158 | 82.9 | 116 |
| ethylbenzene | 5.8 | 11.6 | NA | NA | 11.1 | 11.7 |
| m&p-xylene | 20.9 | 39.3 | 127 | 154 | 40.5 | 30.6 |
| o-xylene | 7.3 | 14.8 | NA | NA | 16.0 | 13.2 |

[a]Chan et al., 1991a. [b]Chan et al., 1991b. [c]SCAQMD, 1989. [d]Reference. [e]This study. NA represents "not available".

terns, and local meteorology influence roadway air concentrations.

The samples collected in the Los Angeles study were measured just before the 1988 California Air Resources Board (CARB) Program was initiated. Presumably, the concentrations would now be lower in California since the regulations have been in place for several years. Hence, the mean levels of benzene and toluene in the present study would now be higher than those of the all cities indicated above in the United States.

3.5 Exposure and Risk Estimations

Exposure to VOCs is a dynamic process, and the average exposure in a microenvironment can be estimated from the average concentration encountered and the amount of time spent there (Lioy, 1990; Ott, 1985). The benzene exposures from different microenvironments were estimated using the following equations:

$$E_i = C_a \times B_r \times F_r / w_t \quad (1)$$

where $E_i$ is inhalation exposure ($\mu g/kg/day$), $C_a$ is air concentration($\mu g/m^3$), $B_r$ is a breathing rate (20 $m^3$/day), $F_r$ is the exposure duration per day, and $w_t$ is the body weight of reference person (70 kg).

According to a public opinion survey in 1995 by Taegu MBC TV station, the exposure duration while commuting were assumed to range from 1.0 to 2.0 hour for a round commute trip. Hence, the typical daily commute time was assumed to be the mean of the commute duration range, 1.5 hour. Since Lioy *et al.*(1991) reported that over 85% of our time is spent in indoor environments, the $F_r$ in outdoor was assumed to be 0.15, and $F_r$ in indoor environments other than the interior of vehicles was calculated to be 0.79. Since cigarette smoke is a confounding source for some gasoline-derived benzene, data from nonsmokers were used to conduct the exposure assessment. The exposures to indoor and outdoor benzene were recalculated using Jo *et al.*'s data (1995), while the in-vehicle exposure was estimated using the data measured in present study.

The cancer risk from benzene exposure was calculated from the estimated exposures. A liberalized model was used to estimate the cancer potency of the benzene exposure (Jo *et al.*, 1990).The model extrapolates animal data at high experimental doses to low environmental exposure levels in order to estimate cancer risk for humans. The model is:

$$R_l = q \times E_i \times 10^{-3} \quad (2)$$

where $R_l$ is lifetime risk, and q is cancer risk potency slope $(mg/kg/day)^{-1}$.

A cancer risk potency slope was calculated using the following equation (Asante- Duah,1993):

$$q = UF_r \times W_t \times 10^3 / B_r \quad (3)$$

where $UF_r$is unit risk factor (risk per $\mu g/m^3$).

A upper-bound unit risk factor of ben-

Table 7. Daily benzene exposure ($\mu g/kg/day$) and life-time cancer risk per ($\mu g/m^3$) estimates in different microenvironments of Taegu

| compound | Indoor | | Outdoor | | Commute | |
|---|---|---|---|---|---|---|
| | expo. | risk | expo. | risk | expo. | risk |
| benzene | 1.47 | $4.3 \times 10^{-5}$ | 0.12 | $3.5 \times 10^{-6}$ | 0.84 | $2.4 \times 10^{-5}$ |

zene, $8.3 \times 10^{-6}$ lifetime cancers per $\mu g/m^3$ benzene (U.S.EPA, 1988), was employed to estimate the cancer risk potency slope, 0.029 $(mg/kg/day)^{-1}$.

Table 7 summarizes the exposure and corresponding risk from three other environments: indoor, outdoor, inside vehicle. When cigarette smoke is eliminated as an indoor air source, the values reported in Table 7 show that the in-vehicle exposure to benzene and corresponding upper-bound cancer risk were about 8 times higher than those for outdoor environment. Even though the time spent in indoor environment was to be more than 13 times more than that in the interior of vehicles, the benzene exposure from indoor environment and corresponding upper-bound cancer risk were only about two times higher than those for the interior of vehicles. This indicates that the vehicle cabin is an important microenvironment for personal exposure to benzene and corresponding cancer risk. It should be noted that in addition to benzene, there were potential health risks from other VOC exposures associated with commutes, since the concentrations of other VOCs were also relatively high (Table 3). It is indicated that since the current benzene exposure data that could be compared the in-vehicle exposure data obtained in this study were not available, the benzene exposure data for indoor and outdoor environments were based on 1995 data (Jo *et al.*, 1995). Hence, the comparisons of benzene exposure and cancer between different microenvironments were conducted in this study, in order to estimate their likely differences.

## 4. Summary and Conclusions

With an allowable measurement precision (less than 20%), we measured six selected aromatic VOCs during idling and while commuting along an urban route. Four driving conditions associated with the use of ACDs were tested for the VOC removal efficiency inside vehicles. It was shown that the two commercial ACDs were not effective for the removal of VOCs in the interior of vehicles, suggesting efforts to develop efficient ACDs for VOC removals. The concentrations of all target VOCs except benzene were significantly higher ($p<0.05$) in the interior of older car than of newer car. The mean levels of benzene and toluene in the present study were well excess of earlier other studies in the United States, besides Los Angeles with which was comparable.

It was indicated that the vehicle cabin is an important microenvironment for personal exposure to benzene and corresponding cancer risk. It was reported that the in-vehicle exposure to benzene and corresponding upper-bound cancer risk were about 8 times higher than those for outdoor environment, the in-vehicle exposure to benzene corresponding upper-bound cancer risk were about half of those from indoor environment. It is noted that this study was conducted in a pilot scale and more extended study on the several different microenvironments is recommended to better understand the mi-

croenvironmental exposures and corresponding cancer risk in the study area.

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Volatile Organic Compound Levels inside Vehicles using Commercia lAir Cleaning Devices

# 상업용 공기정화기 사용 차량 내 휘발성 유기물질 수준

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차량 내부의 높은 휘발성 유기물질 농도와 이들 휘발성 유기물질의 독성 때문에 휘발성 유기물질에 대한 차량 내부에서의 노출이 주요한 관심을 받고 있다. 본 연구에서는 115회의 도시 지역(대구 광역시) 출퇴근과 9회의 정차 실험을 통해 상업용 공기정화기의 6 종류 휘발성 유기물질에 대한 제거 효율이 평가되었다. 네 종류의 운전 조건에서 수행된 정차 및 출퇴근 연구 결과, 본 연구에서 이용된 두 개의 시중 시판 차량용 공기정화기는 휘발성 유기물질에 대해 제거 효율이 없는 것으로 나타났다. 벤젠을 제외한 다섯 종류의 휘발성 유기물질의 농도는 최근 차량보다 오래된 차량 내부에서 높게 나타났다 ($p<0.05$). 본 연구에서 측정된 벤젠과 톨루엔의 평균 농도는 로스앤젤레스에서 측정된 값과 유사하게 나타났고, 그 이외의 미국내 비교지역의 측정값보다는 높게 나타났다. 휘발성 유기물질에 대한 노출 및 해당 발암 위해성은 차량 내부에서 실외 공기의 약 8배 정도 높게, 그리고 실내 공기의 약 절반 정도로 산정 되었다.