

Paint booth volatile organic compounds emissions in an urban auto-repair center

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Abstract: A major concern regarding most auto-repair shops in residential areas is the emission of odorous volatile organic compounds (VOCs) into the local atmosphere, especially during painting operations. VOCs contribute to poor local air quality and are responsible for the perceived odor and discomfort experienced by local residents. Sixteen major VOCs (6 aromatic hydrocarbons and 10 aliphatic carbonyl compounds) were selected as potential target compounds. The site was an auto-repair shop located in a central region of Seoul, South Korea, where the air quality of the site has been a subject of residents' complaints. The sampling points were as follows: 1) in the painting booth with new (NB) or old (OB) removal system, (2) in the exhaust duct after new (ND) or old (OD) odor removal filter, and (3) 2 m below the discharge vent (4 m above the ground) (outdoor air, OA). Each sample was coded: (1) before painting (BP), (2) during painting (DP), and (3) after painting (AP). The toluene level in the duct with the new removal filter during painting (ND-DP) was 1.5 ppm (v/v), while it was 3.8 ppm (v/v) in the right duct with an old removal filter during painting (OD-DP). Accordingly, the effect of filter replacement was reflected by differences in VOC levels. Therefore, accurate monitoring of odorous VOCs is an important step to reduce odor nuisance from local sources.

Key words: VOCs, Toluene, auto-painting operation, indoor air pollution, and painting

1. Introduction

The paints are made up of organic polymers and solvents. The solvents (mainly volatile organic compounds (VOCs)) when vaporized during painting can lead to significant outdoor air pollution in the absence of effective VOC removal filters. There are 3,931 auto-repair shops (centers) at Seoul in the 1st

quarter, 2016 (KMOLIT).¹ Since almost center is located in or near the residential area, nearby residents experience malodor nuisance. In addition to the malodors, some hazardous compounds are emitted from the auto-repair center. Unfortunately, nearby residents are potentially exposed to the harmful compounds. For example, chronic exposure to low VOC concentrations, can lead to irritation of eyes,

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nose or throat.² Therefore, it is necessary to investigate the actual situation and present the solution about that problem.

VOCs include a broad range of organic compounds with boiling points from less than 0 °C to almost 400 °C³ and have vapor pressures (>1 Pa) at a room temperature. Since 1950s, VOCs have been recognized to be the main reactants leading to the photochemical smog in metropolises around the world.⁴ The photochemical reaction of VOCs with nitrogen oxides (NO_x) lead to ozone formation. Additionally, human health concerns have led to the establishment of various regulations to control VOC emissions.⁵ VOCs can cause harm to animals and plants⁶ and are major chemical compounds responsible for odor nuisance.⁷ The international agency for research on cancer (IARC) has classified some VOCs like benzene and formaldehyde as 'Group 1', carcinogens to humans.⁸ In light of VOC environmental concerns, the Korea ministry of environment (KMOE) has issued regulations and guidelines as to the maximum permissible exposure levels for, e.g., formaldehyde,⁹ and toluene, xylene, and styrene.¹⁰

Although some VOCs are naturally produced, e.g., isoprene from flora,¹¹ the main VOC emission sources into the atmosphere are industrial facilities using organic solvent, painting facilities, petrol stations, and transportation.¹²⁻¹⁴ At 2014 in South Korea, total VOC emissions from all painting operations contributed 37 % to the total national VOC emissions inventory. Among those, VOC emission from auto-painting operations represented 2.49 %.¹⁵ Their contributions are low compared to total VOC emissions from all sources. However, their impact on the local VOC pollution levels is often significant because most auto-repair shops in South Korea are located in or near urban residential areas. During automotive painting operations, the VOCs evaporate into the atmosphere from various painting materials (i.e., solvent-based primer, basecoat, and clearcoats).^{5,16} Common paint solvents include aromatic hydrocarbons, esters, ketones, alcohols, and glycolethers.⁵ Gaseous emissions from solvent-based paints generally contain significant quantities of aromatic hydrocarbons such

as toluene and xylene. Paints and coatings contribute significantly to poor air quality especially because they are commonly applied to large surfaces, leading to a high loading factor (surface to volume ratio).¹⁷ Other major anthropological emissions include sewage discharge into the river, landfill, and paving asphalt roads.¹⁸⁻²⁰

Other potentially harmful gases from painting are airborne carbonyl compounds (aldehydes and ketones). Generally, they are either products of incomplete combustion or atmosphere oxidation products of many hydrocarbons and VOCs.^{6,21-23} Carbonyl compounds in the urban atmosphere have been recognized as toxic gaseous contaminants²⁴ and have an adverse effect on human health^{25,26} such as irritation of the eyes and lungs.²⁷ Formaldehyde, acetaldehyde, and acrolein are eye irritants mutagens, and carcinogens.²⁸ Since February 2005, five carbonyl compounds have been designated by the KMOE as offensive odorous compounds: acetaldehyde, propionaldehyde, butyraldehyde, valeraldehyde, and isovaleraldehyde.¹⁰ Also, carbonyl compounds have been extensively studied in quantitative malodor research.²⁹ Thus, this study investigated the concentrations of six aromatic hydrocarbons (benzene, toluene, p-xylene, o-xylene, m-xylene, and styrene) and ten carbonyl compounds (formaldehyde, acetaldehyde, propionaldehyde, butyraldehyde, isovaleraldehyde, valeraldehyde, acrolein, acetone, crotonaldehyde, and benzaldehyde) at an auto-repair center. VOC concentrations were measured inside each of the two painting booths and in their exhaust ducts before and during painting. Outdoor air ~ at 2 m above ground and close to the exterior wall and ~2 m below the booth discharge into the atmosphere was sampled before and after painting.

2. Materials and Methods

2.1. General description of the auto-repair shop

Korea Ministry of Land, Infrastructure, and Transport (KMOLIT) categorized the automotive industry into five sectors; auto-repairing, sales, scrapping, performance checking, and designated maintenance. The total

Table 1. Comparing the number of service center related to Automobile (1st quarter, 2016)

Types	Auto-repair center					Dealing	Scrapping	Checking Performance	Designation repair	Sum
	General	Small	Part	Motor	Sum					
Sum	3,907	1,982	29,330	210	35,429	5,140	520	310	1,690	43,089
Seoul	225	311	3,391	4	3,931	528	0	32	60	4,551
Busan	161	157	1,495	10	1,823	255	10	19	74	2,181
Daegu	151	101	1,430	11	1,693	527	13	23	71	2,327
Incheon	230	102	1,320	5	1,657	300	8	13	73	2,051
Gwangju	167	79	1,071	7	1,324	196	8	7	46	1,581
Daejun	120	39	1,019	8	1,186	211	6	7	36	1,446
Ulsan	99	56	729	4	888	130	9	5	33	1,065
Kyunggi	1,003	536	7,013	63	8,615	1,006	121	75	342	10,159
Gangwon	177	94	1,265	4	1,540	194	35	18	75	1,862
Chungbuk	187	44	1,141	11	1,383	215	33	10	88	1,729
Chungnam	266	69	1,595	19	1,949	271	40	24	136	2,420
Jeonbuk	252	55	1,418	16	1,741	309	49	9	120	2,228
Jeonnam	220	79	1,488	4	1,791	195	55	10	150	2,201
Kyungbuk	270	102	2,121	21	2,514	365	64	28	177	3,148
Kyungnam	298	142	2,310	16	2,766	363	51	25	157	3,362
Jeju	67	11	441	7	526	72	13	4	48	663
Sejong	14	5	83	0	102	3	5	1	4	115

*Korea ministry of land, infrastructure, and transport (KMOLIT), 2016 1st quarter

number of automotive service premises is estimated to be 43,089 in the 1st quarter of 2016¹ (Table 1). About 82 % of those (35,429) are auto-repair shop classified into four major categories: (1) general repairs and service for motor vehicles (general), (2) small repairs to motor vehicles (small), (3) motor vehicles repair services specializing in replacement parts (part), and (4) repair services of motorcycles (motor) according to Korea Standard Industry Classification.³⁰

A general center (legally, >1000 m² repair area) repairs most vehicles (except construction vehicles), replaces vehicle components, and provides vehicles inspections. A small center (legally, >400 m²) repairs cars, small vans, and small trucks replace vehicle parts and conduct vehicles inspections. A part center generally is known as an auto-repair shop is mostly similar to a small center but does not undertake some major repairs such as engine work, anti-lock braking system (ABS) repairs, and sheet metal body repairs. Legally, the work area in a special center should be at least 70 m² if the city population is over 5 million;

otherwise, the work area should generally be larger than 100 m². An engine repair center is legally required to have the work area > 300 m.^{2,31}

Among all the auto-repair shops, replacement part service centers are overwhelmingly common (n=29,330 centers).¹ Therefore, in this study, a 'part' service center located in a residential area was chosen as the sampling site following local residents' complaint.

2.2. Field sample collection

The samples for this study were collected at an automobile repair service center located in Gwangjin-gu, Seoul (127°05.44', 37°32.40') on August 22nd, 2016. This center was installed the adsorption module between each booth and duct line. The sampling points were located in the new removal system booth (NB), in the old system booth (OB), in the ducting from each new (ND) and old booths (OD) before (BP) and during (DP) painting, and the outdoor air (OA) before (BP) and after (AP) painting. The newly system booth is located at left side in the center

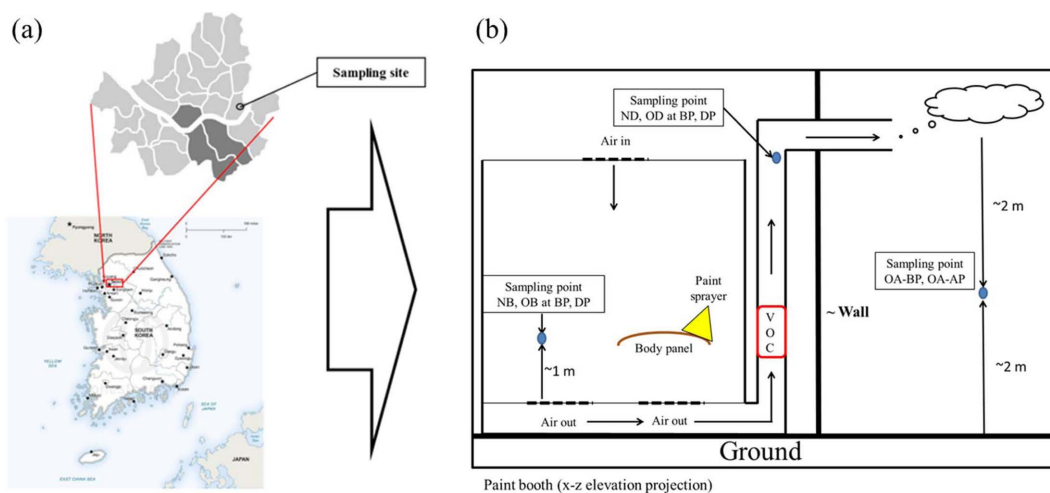


Fig. 1. Schematic representation of the sampling location ((a) Maps showing auto-paint shop location in Seoul, (b): Sampling location)
 *Note 1: B: booth sample, D: duct sample, BP: before painting, DP: during painting
 **Note 2: Comparing the concentration of main VOCs; (a) Toluene, (b) Total xylene (p+m+o-), (c) Formaldehyde, (d) Acetone

Table 2. Information about the samples collected from the auto-repair shop investigated in this work

Sampling order		Sample information		Sample code ^a	Temperature (°C)	Humidity (%)	Wind velocity (m/sec)	Sampling date
2	New installed VOC removal system	In the booth	Before painting	NB-BP	30.8	62.0	0.28	22nd Aug. 2016
3		In the duct		ND-BP	32.7	56.4	0.12	
4		In the booth	During painting	NB-DP	32.7	55.2	0.07	
5		In the duct		ND-DP	32.6	55.8	0.14	
6	Old removal system	In the booth	Before painting	OB-BP	32.5	59.2	0.03	
7		In the duct		OD-BP	32.7	56.4	0.12	
8		In the booth	During painting	OB-DP	31.7	57.4	0.26	
9		In the duct		OD-DP	32.6	55.8	0.14	
1	The outdoor	-	Before painting	OA-BP	33.8	54.8	0.18	
10		-	After painting	OA-AP	33.8	51.0	1.22	

^aNote: NB: New booth, ND: New duct, OB: Old booth, OD: Old duct, OA: Outdoor air, BP: Before painting, DP: During painting, and AP: After painting

while the old system booth is located at right side in the center. The sampling point at each exhaust duct was after the VOC removal module. The sampling at each booth was done at ~1 m above the floor of each booth. When the sampling was done at the outdoor, it was done ~2 m below the outlet and above ~4 m from the ground (Fig. 1).

Table 2 shows the detail information including the sampling points, sample code, and the sampling order. Every time when the samples were collected,

measurements were made for the following variables (e.g., temperature (°C), humidity (%), and wind speed (m/sec) by Air Velocity Meter (Model 9545, TSI, Inc. U.S.A)). All samples were collected in 10 L polyester aluminum (PEA) bags (Top Trading Co. Korea) using two lung-samplers (ACEN, Korea).

Before analysis, a 100 mL aliquot from the 10 L bag was diluted 10 times in N₂ in a 1 L PEA bag (Top Trading Co. Korea) as some samples were expected to contain high VOC concentrations. Subsequently, the

contents of the 1 L PEA bag were pulled through a quartz sorbent tube (ST) packed with Carbopack C, Carbopack B, and Carbopack X (C, B, and X, 50 mg each) by a mini pump (MP-Σ30, SIBATA, Japan) at a flow rate of 100 mL/min for 0.5 min. The sample on the ST was subsequently analyzed as described in the next paragraph.

The six target aromatic hydrocarbon VOCs was chosen were benzene, toluene, p-xylene, m-xylene, o-xylene, and styrene. These compounds were measured using thermal desorption (TD)-gas chromatography-mass spectroscopy (GC/MS). For calibration, the standard samples were prepared by a stepwise dilution of reagent grade chemicals (RGC) with purities of > 95 % (Sigma-Aldrich, USA) in methanol. The injected mass of six target compounds in the standard

samples ranged 4.38~93.6 ng (the case of benzene) for a five-point TD-GC/MS calibration. The detection limits (DL) were determined in heptaplicate using 0.2 µL injections of the 5 ng.µL⁻¹ working standard. The DLs for benzene, toluene, p-xylene, m-xylene, o-xylene, and styrene were 0.57, 0.61, 0.36, 0.33, 0.32, and 1.21 ng, respectively.

For analyzing the carbonyl compounds, a DNPH-cartridge (for carbonyl compound derivatization) was connected to each 10 L site sampling PEA bag. The bag contents were pulled through at a flow rate of 1 L/min for 5 min using a mini pump (MP-Σ30, SIBATA, Japan). After the sampling, the DNPH cartridge was eluted with 5 mL of acetonitrile and 10 µL of the extract was loop-injected on HPLC/UV for subsequent analysis and quantification.

Table 3. Instrumental (TD-GC/MS and HPLC/UV) conditions for the analysis of aromatic hydrocarbons and carbonyl compounds

<i>a. Gas Chromatography (GC) setting</i>			
GC (SHIMADZU GC2010, JAPAN) and MS (SHIMADZU GCMS-QP2010, JAPAN)			
Column: CP Wax (length: 60 m, diameter: 0.25 mm, and film thickness: 0.25 µm)			
(1) Oven setting		(2) Detector setting	
Oven temp.:	40 °C (10 min)	Ionization mode:	EI (70eV)
Oven rate:	6 °C min ⁻¹	Ion source temp:	230 °C
Max oven temp.:	220 °C (10 min)	Interface temp:	230 °C
Total time:	50 min	TIC scan range:	35-500 m/z
		Scan speed	1250 amu/sec
Sampling tube			
Adsorbent:	Carbopack C + Carbopack B + Carbopack X (50 mg each)		
Desorb time:	5 min	Desorb temp:	320 °C
Desorb flow:	100 mL·min ⁻¹		
Thermal Desorber (UNITY2, Markes International, Ltd., UK)			
Cold trap:	Carbopack C + Carbopack B (1:1)		
Split ratio:	1:10	Trap low:	-25 °C
Split flow:	10 mL·min ⁻¹	Trap high:	320 °C
Trap hold time:	5 min	Flow path temperature:	190 °C
<i>b. High-Performance Liquid Chromatography (HPLC) setting</i>			
HPLC/UV (Spectrasystem UV 2000, ThermoFisher scientific, USA)			
Column: C18 (5 µm, 2.1 × 250 mm, Acclaim 120 C18)			
(1) Analysis setting		(2) Detector setting	
Acetonitrile:H ₂ O	70:30	Detector:	360 nm UV
Flow rate:	1.5 mL min ⁻¹		
Injection:	20 µL		
Time:	20 min		

Ten target carbonyl compounds selected were formaldehyde (FA), acetaldehyde (AA), propionaldehyde (PA), butyraldehyde (BA), iso-butyraldehyde (IA), valeraldehyde (VA), acrolein, acetone, crotonaldehyde (CA), and benzaldehyde (BZA). HPLC/UV calibration was carried out using liquid-phase working standards prepared by diluting the TO11.IP-6Aldehyde/Ketone-DNPH Mix (Supelco, USA) in a stepwise manner in acetonitrile. For a five-point calibration, the mass range of the ten carbonyl compounds was 3-60 ng (in the case of formaldehyde). For calculating the detection limit (DL), propionaldehyde with the smallest peak area was chosen. The DLs for FA, AA, acrolein, acetone, PA, CA, BA, BZA, IA, and VA were 0.79, 1.00, 1.13, 1.30, 1.29, 1.52, 1.61, 2.35, 1.87, and 1.92 $\mu\text{g}/\text{m}^3$ for, respectively for a 5 L sample.

Both the calibration and QA/QC data were obtained prior to the analysis of the auto-repair paint-shop samples. The response factor (RF) (ng^{-1}) of the TD-

GC/MS system for target VOCs was from 32,200 (S) to 126,952 (o-X). The RF (ng^{-1}) of UV/HPLC system was from 4,871 (BZA) to 14,458 (FA). The coefficient of determination (R^2) values of all target compounds in the calibration were >0.9889 .

2.2. Instrumental setup

The target aromatic hydrocarbons were analyzed by a GC/MS (Shimadzu GCMS – QP2010, Japan) equipped with thermal desorption unit (Unity 2, Markes International Ltd., UK). The cold trap (CT) in the TD unit was packed with Carboxpack C and Carboxpack B in a one-to-one volume ratio. Analytes loaded on the ST were desorbed at 320 °C and transferred to the CT maintained at – 25 °C. Finally, the analytes in the CT was then desorbed at 320 °C for 5 min to be transferred to a CP wax column (60 mL \times 0.25 mm ID \times 0.25 μm film thickness) for separation. The temperature in the GC oven was set at 40 °C for

Table 4. Results of analysis of aromatic hydrocarbons and carbonyl compounds measured in paint-shop samples and VOC permissible levels (in ppb)

Target Compounds	ACGHI ^a (ppb)	OSHA ^b (ppb)	Concentration (ppb)										Odor ^c Threshold
			NB-BP	NB-DP	OB-BP	OB-DP	ND-BP	ND-DP	OD-BP	OD-DP	OA-BP	OA-AP	
Sampling order			2	3	4	5	6	7	8	9	1	10	
<i>a. Volatile organic compounds</i>													
Benzene	630	10,000	4.11	3.85	1.77	<u>0.18</u>	3.06	<u>0.18</u>	<u>0.18</u>	<u>0.18</u>	2.70	2.36	2,700
Toluene	50,000	200,000	394	593	464	940	260	1,528	1,261	3,868	176	23.7	330
p-Xylene	100,000	-	20.6	47.7	121	84.5	7.57	289	139	197	2.69	1.31	58.0
m-Xylene	100,000	-	47.7	110	275	193	17.6	661	322	457	6.36	2.59	41.0
o-Xylene	100,000	-	30.1	62.1	168	102	10.0	382	195	297	2.32	1.55	380
Styrene	20,000	100,000	36.7	<u>0.29</u>	30.7	42.2	31.7	17.9	<u>0.29</u>	<u>0.29</u>	<u>0.29</u>	<u>0.29</u>	35.0
<i>b. Carbonyl compounds</i>													
Formaldehyde	325	730	16.9	9.84	14.0	12.8	13.0	18.0	20.1	20.3	9.27	7.24	500
Acetaldehyde	25,000	200,000	1.66	4.36	3.35	2.69	3.30	14.5	5.51	5.52	4.41	3.87	1.50
Propionaldehyde	20,000	-	<u>0.55</u>	1.45	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	3.29	1.69	1.55	<u>0.55</u>	<u>0.55</u>	1.00
Butyraldehyde	-	-	<u>0.55</u>	2.51	1.08	5.74	2.47	13.1	3.32	22.4	0.66	0.60	0.67
Isobutyraldehyde	-	-	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	0.35
Valeraldehyde	50,000	-	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	0.41
Acrolein	110	150	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	<u>0.50</u>	3.60
Acetone	380,000	760,000	115	330	110	816	316	1,172	114	1,559	57.3	39.1	42,000
Crotonaldehyde	300	2,000	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	<u>0.54</u>	23.0
Benzaldehyde	-	-	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	<u>0.55</u>	-

^aThreshold Limit Value set by American Conference of Governmental Industrial Hygienists (2004)

^bPermissible Exposure Level set by the Occupational Safety and Health Administration (2004)

^cNigata and Takeguchi, Bulletin of Japan Environmental Sanitation Center (1990)

Under the detection limit

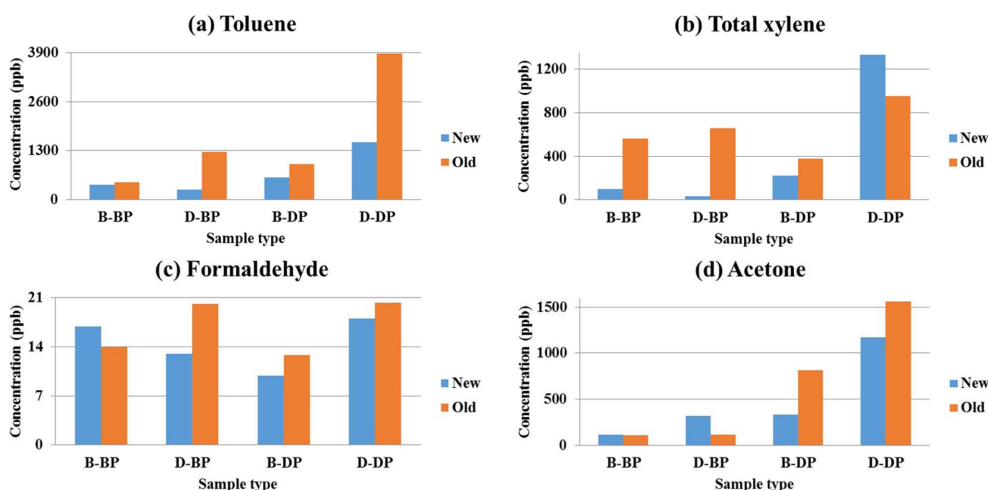


Fig. 2. The concentration of major VOCs at the sampling locations before and during paint spraying.

*Note: Wind speed (m/sec); OA-BP: 0.18 m/sec, OA-AP: 1.22 m/sec

10 minutes and ramped to 22 °C for 10 minutes at 6 °C/min (Table 4).

The analysis of the 10 target carbonyl compound hydrazones was performed on HPLC/UV (Spectra-system UV 2000, ThermoFisher scientific, USA) equipped with a C18 column (5 μ m, 2.1 \times 250 mm, Acclaim 120 C18, ThermoFisher Scientific, USA) and a loop injector. Elution was done with a mixture of acetonitrile and distilled water (70:30 ratio), as the mobile phase at a flow rate of 1.5 mL/min for a total run time of 20 minutes; detection was made by a UV detector at 360 nm (Table 4).

3. Results and Discussion

In this study, total 10 gaseous samples (8 indoor samples and 2 outdoor samples) were collected using 10 L PEA sampling bags and the concentrations of 16 target compounds in all were determined. Among those, 5 compounds (IA, VA, Acrolein, CA, and BZA) were not detected in any samples. In contrast, toluene was detected with the highest concentration range of 400 ~ 4,000 ppb in the 8 indoor samples; NB-BP: 394 ppb, NB-DP: 593 ppb, OB-BP: 464 ppb, OB-DP: 940 ppb, ND-BP: 260 ppb, ND-DP: 1,528 ppb, OD-BP: 1,261 ppb, and OD-DP: 3,868 ppb. In the two outdoor samples, toluene and acetone

recorded the highest concentration values such as [1] 176 (T) and 57.3 ppb (ACT) in OA-BP and [2] 23.7 (T) and 39.1 ppb (ACT) in OA-AP (Table 4).

In Fig. 2, concentrations of the VOCs (toluene, xylene, formaldehyde, and acetone) were compared. The concentrations of p-xylene, m-xylene, and o-xylene are given as total xylene. Before painting, their concentrations in the booths and duct were similar. In case of toluene, the concentrations in the booth and duct with new system were 394 and 260 ppb, respectively. At during painting, the concentration of main VOCs in new booth is lower than the concentration in old booth. The concentration except xylene in the duct from new booth also is lower than the concentration in the duct from old booth (Fig. 2).

In the case of B-BP samples, the concentrations of toluene and total xylene from old system are about 1.17 to 5.73 times higher than the concentrations from new system; toluene: 394 vs. 464 ppb and total xylene: 98.4 vs. 564 ppb (Fig. 2 and Table 4). Although the painting did not operated, the reason for this remarkable differences was the difference of the ventilation capacity depending on the system replacement.

In Fig. 3, this study arranged the concentration results of toluene, total xylene, formaldehyde, and acetone in OA samples. BP samples is about 1.28 to

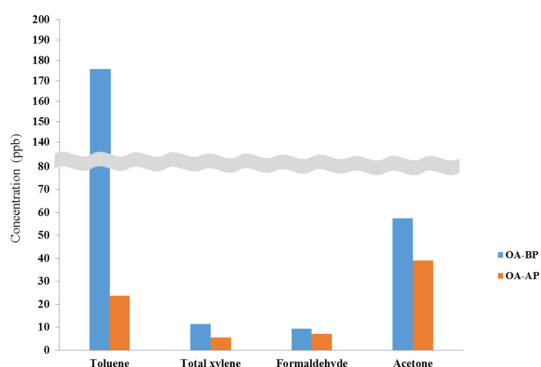


Fig. 3. Concentration of the major VOCs at outside sampling point before and after painting.

7.43 times higher than AP samples; toluene: 176 vs. 23.7 ppb, total xylene: 11.37 vs 5.45 ppb, formaldehyde: 9.27 vs. 7.24 ppb, and acetone: 57.3 vs. 39.1 ppb. The reason for this results is the difference of the wind speed between OA-BP (0.18 m/sec) and OA-AP (1.22 m/sec) (Table 2). Due to these variable, it is assumed that the target compounds has diffused.

The toluene concentrations in NB-DP and OB-DP (593 and 940 ppb) in the present work are about 2 or 4 times higher than those found in aeronautical industry spraying of about 259 ppb.³² During the coating process in the manufacture of polyuria-formaldehyde resin synthetic leather, toluene concentration in coating duct (about 1,320 ppm) was about 1,400 and 2,200 times higher than NB-DP and OD-DP.³³ The average ambient air toluene concentration measured by an automated hydrocarbon measurement system at Jong-Ro, Seoul was about 6 ppb over a 3-year period (2013-2015).³⁴

The results of this study imply that the VOC concentrations are far below the prolonged exposure limits set by American Conference of Governmental Industrial Hygienists³⁵ or the permissible exposure level set by the Occupational Safety and Health Administration³⁶ and thus posed a minimal health risk to humans. Nevertheless, a continuous exposure at the low concentration of VOCs causes, for example, irritation of eye, nose or throat.² Especially, toluene has a risk to cause an anemia and cancer.³⁷ Chronic exposure to low concentrations of toluene can cause neurobehavioral effects³⁸ and effects on the central

nervous system.³⁹ Acetaldehyde in OD samples had exceed the standard of the odor threshold.⁴⁰

4. Conclusions

This study measured concentrations of 16 VOCs in a small-scale urban auto-paint spraying center. Among the 16 target VOCs, the concentrations of 5 VOCs; isovaleraldehyde, valeraldehyde, acrolein, crotonaldehyde, and benzaldehyde were under 1 ppb which is below the instrument detection limit. In contrast, the concentration of toluene was the highest (ranging between 400 ~ 4,000 ppb) among all VOCs followed by acetone (40 ~ 1,500 ppb) and formaldehyde (<50 ppb). The recorded indoor-air toluene levels in the present work were about 2 or 4 times higher than the aeronautical spraying operations but were generally lower than the levels recorded during painting and coating processes in the synthetic leather industry. Overall, results of this study indicated that the VOC concentrations in outside air ~2 m below the paint-shop exhaust port were well below the prolonged exposure limits set by ACGIH or OSHA.

The difference in the toluene results between the ND-DP (1,528 ppb) and OD-DP (3,868 ppb) samples is due to a recent replacement of a spent odor removal with a new one in the left duct. Continuous emissions monitoring is needed to ensure compliance with various regulations. One of the biggest social concerns considering urban auto-repairing centers is odor nuisance. The responsible government agencies should ensure regular upkeep and replacement as needed of the VOC removal units in paint booths.

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