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A Study on Optimal Combination of Adsorbents for Sampling of C_4-C_{10} Hydrocarbons in Ambient Air and Analysis with Thermal Desorption Gas Chromatography Coupled with Mass Spectrometry (GC/MS)

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This study was carried out to evaluate the sampling performance and analytical methodology for the measurement of hydrocarbons in ambient air. Usually C_4-C_{10} hydrocarbons are determined with adsorbent tube sampling and automatic thermal desorption gas chromatography coupled with mass detector (GC/MS). In this study we determined 56 compounds including hazardous air pollutants such as, benzene, toluene, ethyl benzene, xylenes, 1,3-butadiene and halogenated hydrocarbons, *etc*. The methodology was investigated with a wide range of different adsorbents which are commercially available and frequently adopted for the volatile organic compounds measurement. From four adsorbents are tested which are three carbon-based adsorbents such as, carbograph 2TD, carbograph 1TD and carbopack X and one polymer-based adsorbent (Tenax TA). We compare the efficiencies of the single adsorbent and multiple adsorbents with respect to volatile organic compounds adsorption. The results indicates that the most suitable combination for C_4-C_{10} hydrocarbon measurements is triple adsorbent tube containing carbograph 2TD, carbograph 1TD and carbopack X. This method was found to be well suitable for the sampling of a broad range of volatile organic compounds in ambient air compare to the traditional methods. The sampling performance was evaluated with respect to the safe sampling volume of volatile organic compounds with a single adsorbent and multiple adsorbents for standard and field samples.

Keywords: Volatile organic compounds, Adsorbents, Benzene, Ambient air sampling, GC/MS.

INTRODUCTION

Monitoring of hydrocarbons in ambient air is became an important task to the researchers in worldwide due to their toxic effects on human health. In two aspects the monitoring of atmospheric hydrocarbons gains more attention of the researchers. First, the olefin hydrocarbons have a potential to form photochemical smog by the reaction with secondary ozone and oxidizing substances like aldehydes[1]. Second, halogenated and aromatic hydrocarbons are directly harmful to the humans with respect to their health[2]. Among the hydrocarbons (C_4-C_{10}) especially for the substances like 1,3-butadiene and benzene, toluene, ethyl benzene, xylenes (BTEX) require intensive measurement and analysis due to high risk to the environment and humans. The clean air act[3] of the USA listed 187 substances as hazardous air pollutants including a number of hydrocarbons such as, BTEX and 1,3-butadiene *etc*. The international agency for research on cancer (IARC) listed benzene and 1,3-butadiene as group 1 carcinogens which are carcinogenic to humans. Benzene which is mostly found in urban atmosphere causes acute myeloid leukemia/acute non-lymphocytic leukemia while 1,3-butadiene causes cancer to the haematolymphatic organs[4]. The toxic and carcinogenic nature to human and production of secondary air pollutants by the volatile organic compounds needs the accurate measurement to assess the quality of air.

Canisters and adsorbent tubes are mostly using for the collection of volatile organic compounds in ambient air in worldwide. However, both methods have strengths as well as weaknesses. Sampling through the canisters has the advantages such as, there is no breakthrough of target compounds, relatively easy to grab the samples and there is no requirement of thermal desorption. The usage of canisters for sampling of volatile organic compounds in ambient air in various parts of the world was reported by several authors[5-9]. The sampling of volatile organic compounds by using canisters has some limitations such as, expensive cost, storage of samples required specific conditions of temperature, pressure and they are not applicable to collect polar volatile organic compounds. Due to these limitations many authors in worldwide preferred adsorbent tubes containing single and/or multiple adsorbents over canisters[10-16]. The advantages of adsorbent sampling over

canister sampling are convenient, portable and suitable for wide range of analytes including polar and non-polar volatile organic compounds. In addition to this advantages, the drawback of adsorbent sampling is not suitable for collecting C_1-C_3 hydrocarbons. There is a chance for breakthrough for analyte during sampling and formation of artifact. Therefore, to select the appropriate sampling method depends on several parameters should be taken into consideration such as, type of analyte, moisture, temperature and the concentration range of the target analytes.

The removal or determination of volatile organic compounds in ambient air can be processed through numerous physical and chemical methods[17,18]. The determination or removal of volatile organic compounds by adsorption method is more familiar due to ease of sampling. Now a days a number of adsorbents are available to determine the volatile organic compounds in ambient air and they are broadly divided into polymer resin based and carbon based adsorbents. Polymer resin based adsorbents like Tenax TA[19], XAD-2, XAD-4 and XAD-16[20] were used for the determination of volatile organic compounds in ambient air by many researchers in worldwide. Similarly, the carbon based adsorbents like Carbopack X[21], Carbotrap, Carbopack B, Carbosieve-SIII and Carboxen 569[22,23] were also evaluated for the analysis of ambient volatile organic compounds. Among these, the popular resin based adsorbent Tenax TA and carbon based adsorbents such as, Carbograph 2TD, Carbograph 1TD and Carbopack X were selected for the present study to evaluate the optimal combination for the adsorption of volatile organic compounds in ambient air. Among these adsorbents, Carbograph 1TD has medium strength to adsorb the volatile organic compounds where as Carbograph 2TD and Tenax TA are relatively weaker than this and Carbopack X is stronger. Carbopack X is good to collect the low molecular weight hydrocarbons and not good for high molecular weight compounds due to poor desorption performance. Like this every single adsorbent has merits and demerits and any single adsorbent is not suitable to collect a wide range of volatile organic compounds in ambient air. It forces us to develop a method to collect wide range of volatile organic compounds in ambient air by using different combinations of the above said adsorbents.

In this study, we have investigated an optimal combination of adsorbents for effective sampling of volatile organic compounds in ambient air, focusing on single and/or multiple adsorbent tubes containing Tenax TA, Carbograph 2TD, Carbograph 1TD and Carbopack X. The adsorption efficiencies of single, double and triple adsorbents with respect to C_4-C_{10} volatile organic compounds are evaluated using a standard gas mixture of volatile organic compounds and the method was applied for field samples collected at an industrial site in Korea. All the adsorbent samples were analyzed thermal desorption gas chromatography coupled with mass spectrometry (GC/MS) system.

EXPERIMENTAL

Configuration of adsorbent tubes: In this study, we tested the performance of a polymer based adsorbent Tenax TA which can adsorb a wide range of hydrocarbons and a series of high performance carbon adsorbents such as, Carbograph 2TD, Carbograph 1TD and Carbopack X. The characteristics of the selected absorbents used for volatile organic compounds sampling are summarized in Table-1. The hydrophobic nature of adsorbents excludes the moisture effect and also suitable for the adsorption of volatile organic compounds in ambient air. The thermal stability of these adsorbents is up to 350 °C which prevents the deactivation of the adsorbent.

To evaluate the performance of the adsorbents, we tested three types of single adsorbents (Tenax TA, Carbograph 1TD and Carbopack X) and the combination of multiple adsorbents (double and triple). Due to weak adsorption of hydrocarbons by the Carbograph 2TD even than Tenax TA, we excluded the testing of single adsorbent of Carbograph 2TD. In the process of making the single and multiple adsorbent tubes, stainless tubes (9 cm × 1/4″, Perkin Elmer, UK) are used. The filling of adsorbents and appearance of single, double and triple adsorbent tubes are schematically represented in Fig. 1. The adsorbent tube has 6 cm heating zone and the adsorbents are always filled in this heating zone. In case of double and triple adsorbent tubes they are filled with adsorbents in a manner that first the air enters into the weak adsorbent followed by the medium and/or strong adsorbent (s) (Fig. 1).

Process of making the adsorbent tube (s): In the process of making the adsorbent tubes with single, double and triple adsorbents, first the tubes are fixed with the gauze and with unsilanized glass wool and then the weighed adsorbent are added with funnel. The gauze loading rig (Gauze Loading Rig, Perkin Elmer Inc., UK) is used to pack the adsorbent in adsorbent tube. The accurate weight of the adsorbent is measured with a chemical balance (AEX-200G, SHIMADZU Inc., Japan). In case of double or triple adsorbents each adsorbent is separated with the glass wool. Finally after compressing the adsorbent (s), spring is put into the adsorbent tube with gauze loading rig to fix the adsorbent (s).

Conditioning of tubes: Before sampling the adsorbent tubes are conditioned to remove impurities which exist in adsorbent tubes. In this study, pre-treatment of tubes is performed with thermal conditioner (TC-20, Markes Inc., UK) using a high-purity helium gas 80 mL/min under flowing conditions. Each adsorbent tube is treated by applying the temperature of 250 °C for 1 h and 300 °C for another 1 h. After pretreatment all the adsorbent tubes are capped with tube caps (Swagelok, UK) and put in 50 mL glass vial and stored at room temperature.

TABLE-1
CHARACTERISTICS OF SELECTED ADSORBENTS USED FOR VOLATILE ORGANIC COMPOUNDS SAMPLING

Type	Adsorbent	Analyte range	Mesh size	Specific surface area (m^2/g)	Max. temp. (°C)	Strength
Polymer based	Tenax TA	n-C_7 to n-C_{26}	60-80	35	350	Weak
Carbon based	Carbograph 2TD	n-C_8 to n-C_{20}	40-60	100	400	Weak
	Carbograph 1TD	n-$C_{5/6}$ to n-C_{14}	40-60	100	400	Medium
	Carbopack X	n-$C_{3/4}$ to n-$C_{6/7}$	40-60	100	400	Strong

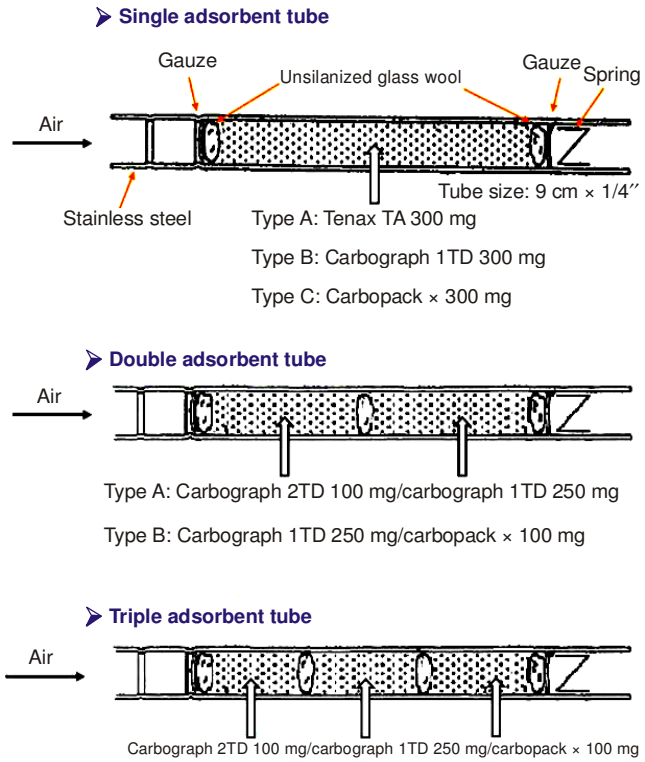


Fig. 1. Schematic diagrams of different combinations of adsorbent tubes

Impregnation of standard gas mixture: In order to evaluate the adsorption performance with respect to C_4-C_{10} hydrocarbons by the different adsorbents, a standard gas mixture (1 ppm nominal, Supelco Inc., USA) mentioned in US EPA TO-15 method was used. The standard gas mixture includes 62 species belonging to the different categories of volatile organic compounds including aliphatic, aromatic hydrocarbons and heterogenic substances. The physico-chemical characteristics of these 62 volatile organic compounds standard gas mixture are presented in Table-2.

We selected benzene as an indicator to represent the concentration level with mass to volume basis. Spiking the gas mixture on to clean tubes was carried out with a self-assembled impregnation system (Fig. 2). We tested three different types of benzene amounts present in standard gas mixture such as, 25 ng (30 sec impregnated with 15 mL/min), 50 ng (30 sec impregnated with 30 mL/min) and 100 ng (60 sec impregnated with 30 mL/min). The impregnation of standard gas mixture into the adsorbent tubes is shown in Fig. 2. By adjusting the impregnation time and flow rate of the standard gas mixture the amount and concentrations of volatile organic compounds in the standard adsorbed into the adsorbent tube is to be controlled. The flow rate is adjusted with the help of 3-way valve connected to dummy, standard and standard gas mixture cylinder.

TABLE-2
PHYSICOCHEMICAL CHARACTERISTICS OF VOLATILE ORGANIC COMPOUNDS STANDARD GAS MIXTURE

No.	Compounds	CAS No.	Ist Ion	M.W.	B.P. (°C)	No.	Compounds	CAS No.	Ist Ion	M.W.	B.P. (°C)
1	Propylene	115-07-1	41	42.08	-47.4	32	1,2-Dichloropropane	78-87-5	63	112.99	96.8
2	Ethanol	64-17-5	45	46.07	78.3	33	1,4-Dioxane	123-91-1	88	88.11	101.0
3	Freon 12	75-71-8	85	120.91	-29.8	34	Bromodichloromethane	75-27-4	83	163.83	90.1
4	Chloromethane	74-87-3	50	50.49	-24.2	35	Trichloroethylene	79-01-6	95	131.39	86.7
5	Freon 114	76-14-2	85	170.92	3.8	36	Heptane	142-82-5	43	100.20	98.4
6	Vinyl chloride	75-01-4	62	62.50	-13.9	37	4-Methyl-2-pentanone	108-10-1	43	100.16	117.4
7	1,3-Butadiene	106-99-0	39	54.09	-4.4	38	*Cis*-1,3-dichloropropene	10061-01-5	75	110.97	104.3
8	Bromomethane	74-83-9	94	94.94	3.6	39	Trans-1,3-dichloropropene	10061-02-6	75	110.97	112.0
9	Chloroethane	75-003	64	64.52	12.3	40	1,1,2-trichloroethane	79-00-5	97	133.40	113.8
10	Acetone	67-64-1	43	58.08	56.2	41	Toluene	108-88-3	91	92.14	110.6
11	Isopropyl alcohol	67-63-0	45	60.10	82.4	42	Methyl-*n*-butyl ketone	591-78-6	43	100.16	127.0
12	Freon 11	75-69-4	101	137.37	23.8	43	Dibromo chloromethane	124-48-1	127	208.28	120.0
13	1,1-Dichloroethene	75-35-4	61	96.94	31.7	44	1,2-Dibromoethane	106-93-4	107	187.86	131.7
14	Methylene chloride	75-09-2	49	84.93	39.8	45	Tetrachloroethylene	127-18-4	166	165.83	121.1
15	Freon 113	76-13-1	101	187.38	47.6	46	Chlorobenzene	108-90-7	112	112.56	130.0
16	Carbon disulfide	75-15-0	76	76.13	46.2	47	Ethylbenzene	100-41-4	91	106.17	136.2
17	*Trans*-1,2-dichloroethylene	156-60-5	61	96.94	47.5	48	*m*-Xylene	108-38-3	91	106.17	139.1
18	Methyl tert-butyl ether	1634-04-4	73	88.15	55.2	49	*p*-Xylene	106-42-3	91	106.17	138.3
19	1,1-Dichloroethane	75-34-3	63	98.96	57.3	50	Bromoform	75-25-2	173	252.73	149.5
20	Vinyl acetate	108-05-4	43	86.09	72.3	51	Styrene	100-42-5	104	104.15	145.2
21	Methyl ethyl ketone	78-93-3	43	72.11	79.6	52	1,1,2,2-tetrachloroethane	79-34-5	83	167.85	146.3
22	*Cis*-1,2-dichloroethylene	156-59-2	61	96.94	60.0	53	*o*-Xylene	95-47-6	91	106.17	144.0
23	Ethyl acetate	141-78-6	43	88.11	77.1	54	4-Ethyltoluene	622-96-8	105	120.19	162.0
24	Hexane	110-54-3	57	86.18	69.0	55	1,3,5-trimethylbenzene	108-67-8	105	120.19	165.0
25	Chloroform	67-66-3	83	119.38	61.7	56	1,2,4-trimethylbenzene	95-63-6	105	120.19	169.0
26	Tetrahydrofuran	109-99-9	42	72.11	66.0	57	Benzyl chloride	100-44-7	91	126.59	179.3
27	1,2-Dichloroethane	107-06-2	62	98.96	83.5	58	1,3-Dichlorobenzene	541-73-1	146	147.00	173.0
28	1,1,1,-Trichloroethane	71-55-6	97	133.40	74.1	59	1,4-Dichlorobenzene	106-46-7	146	147.00	173.4
29	Benzene	71-43-2	78	78.11	80.0	60	1,2-Dichlorobenzene	95-50-1	146	147.00	180.5
30	Carbon tetrachloride	56-23-5	117	153.82	76.7	61	1,2,4-Trichlorobenzene	120-82-1	180	181.45	214.4
31	Cyclohexane	110-82-7	56	84.16	80.7	62	Hexachloro-1,3-butadiene	87-68-3	190	260.76	210.0

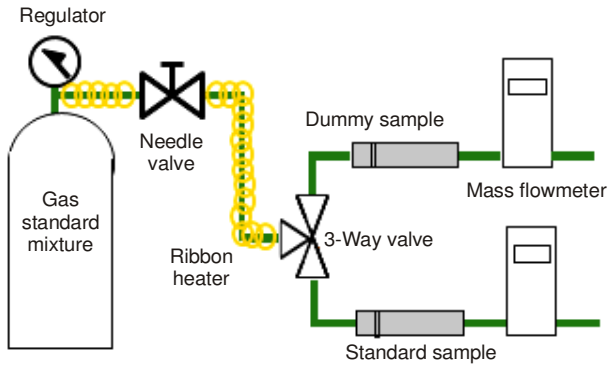


Fig. 2. Impregnation system for volatile organic compounds standard gas mixture

Collection of real field samples: This study evaluates the adsorption performances of adsorbents not only in standard gas mixture but also in real field samples. For this purpose, we used four types of adsorbent tubes including single, double and triple adsorbents for real air sampling simultaneously with the lab experiments. The real field samples (n = 10) are collected simultaneously for 5 days (morning and afternoon) at an industrial complex located in Pohang city of South Korea by using FLEC air pump 1001 (Field and laboratory emission cell, Chematec Inc., Denmark) at a flow rate of 100 mL/min with a sampling duration of 3 h.

Volatile organic compounds analysis: The quantitative analysis of volatile organic compounds collected through the adsorbent tubes was performed by an automatic thermal desorber (UNITY/ULTRA, Markes, UK) coupled with capillary gas chromatography fitted with a mass detector (HP 6890/5973, Hewlett-Packard, USA). Analytical and operating conditions of this system are summarized in Table-3. Thermal desorption of volatile organic compounds was carried out in two steps *i.e.*, primary and secondary desorption. The primary desorption was carried out at 300 °C with a flow rate at 50 mL/min about 10 min in which the eluted volatile organic compounds were swept from the sampling tube to a cryofocusing trap (packed with Tenax TA/Carbotrap) maintained at -15 °C. The secondary desorption was carried out by rapid heating of cold trap from -15 to 320 °C and maintained at this temperature for 5 min. During this period the volatile organic compounds were effectively injected as a narrow band onto a Rtx-1 capillary column (0.32 mm, 105 m, 1.5 µm film thickness, RESTEK Corp., USA). The column oven temperature was initially maintained at 50 °C for 10 min and increased it at a rate of 5 °C/min to reach 250 °C and maintained at this temperature for 5 min. The transfer line and valves of the automatic thermal desorber were heated at 180 °C. The flow of the carrier gas (helium) in the analytical column was approximately 1.4 mL/min (15 psi) and the outlet split flow of the automatic thermal desorber was 10 mL/min. The quality control for the analysis of volatile organic compounds is followed as described in our previous research paper[24]. The typical chromatograms of standard gas mixture and real field samples with the combination of triple adsorbents are shown in Fig. 3.

TABLE-3
ANALYTICAL CONDITIONS FOR VOLATILE ORGANIC COMPOUNDS WITH THERMO-DESORPTION GC/MSD

Thermal Desorber UNITY/ULTRA (Markes, UK)		GC/MSD (HP6890/5973, Hewlett Packard, USA)	
Oven temp.	300 °C	GC column	Rtx-1 (0.32 mm, 105 m, 1.5 µm)
Desorb time	10 min	Initial temp.	50 °C (10 min)
Desorb flow	50 mL/min	Oven ramp rate	5 °C/min
Cold trap holding time	5 min	Final temp.	250 °C (5 min)
Cold trap high temp.	320 °C	Post run	250 °C (5 min)
Cold trap low temp.	-15 °C	Column flow	1.4 mL/min
Cold trap packing	Tenax TA/ Carbopack B	Detector type	Quadropole
Min. pressure	15 psi	Q-pole temp.	150 °C
Inlet split	No	MS Source temp.	230 °C
Outlet split	10 mL/min	Mass range	35-300 amu
Valve and line temp.	180 °C	Electron energy	70 eV

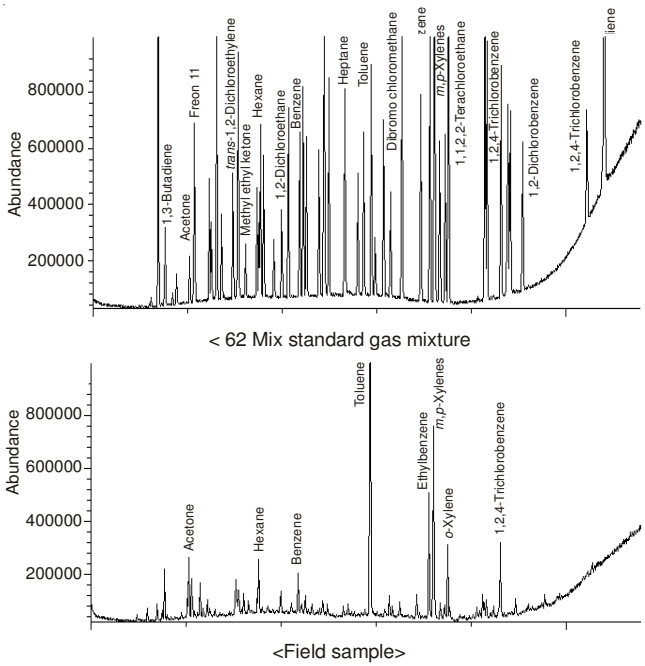


Fig. 3. Typical chromatograms of triple adsorbent tube for the standard and sample.

RESULTS AND DISCUSSION

To evaluate the performance of the different combinations of adsorbents we measured their absolute response factor for comparison. The absolute response factor values are calculated by dividing the area obtained for specific compound in the chromatogram with its amount. The absolute response factor values are useful to avoid the analytical errors during the impregnation of standard into the adsorbent tubes.

In this study the absolute response factor values for the different combinations of adsorbents with hydrocarbons present in standard gas mixture are evaluated. This standard gas mixture is impregnated into the adsorbent tubes having 25, 50 and 100 ng as benzene amounts. The adsorption performances of different combinations of adsorbents towards C_4-C_{10} hydrocarbons are predicted based on the ratio between the absolute response factor of the selected adsorbent and to the absolute response factor value of the Carbograph 1TD, the absolute response factor value of the later is considered as unit.

The total hydrocarbons present in the standard gas mixture is divided into two types that are homogeneous containing only carbon and hydrogen and another is heterogeneous containing a hetero atoms like oxygen and/or halogen along with carbon and hydrogen. The adsorption performance of the single and multiple combinations of adsorbents towards 56 volatile organic compounds including both homogenous and heterogeneous hydrocarbons is shown in Fig. 4. Due to low molecular weight of a few volatile organic compounds were not adsorbed on to the adsorbents from standard gas mixture containing 62 volatile organic compounds. From this Fig. 4 it is clearly observed that Carbopack X either in single and multiple combinations effectively adsorbs the low molecular weight hydrocarbons such as, Freon 12 and ethyl chloride. But the

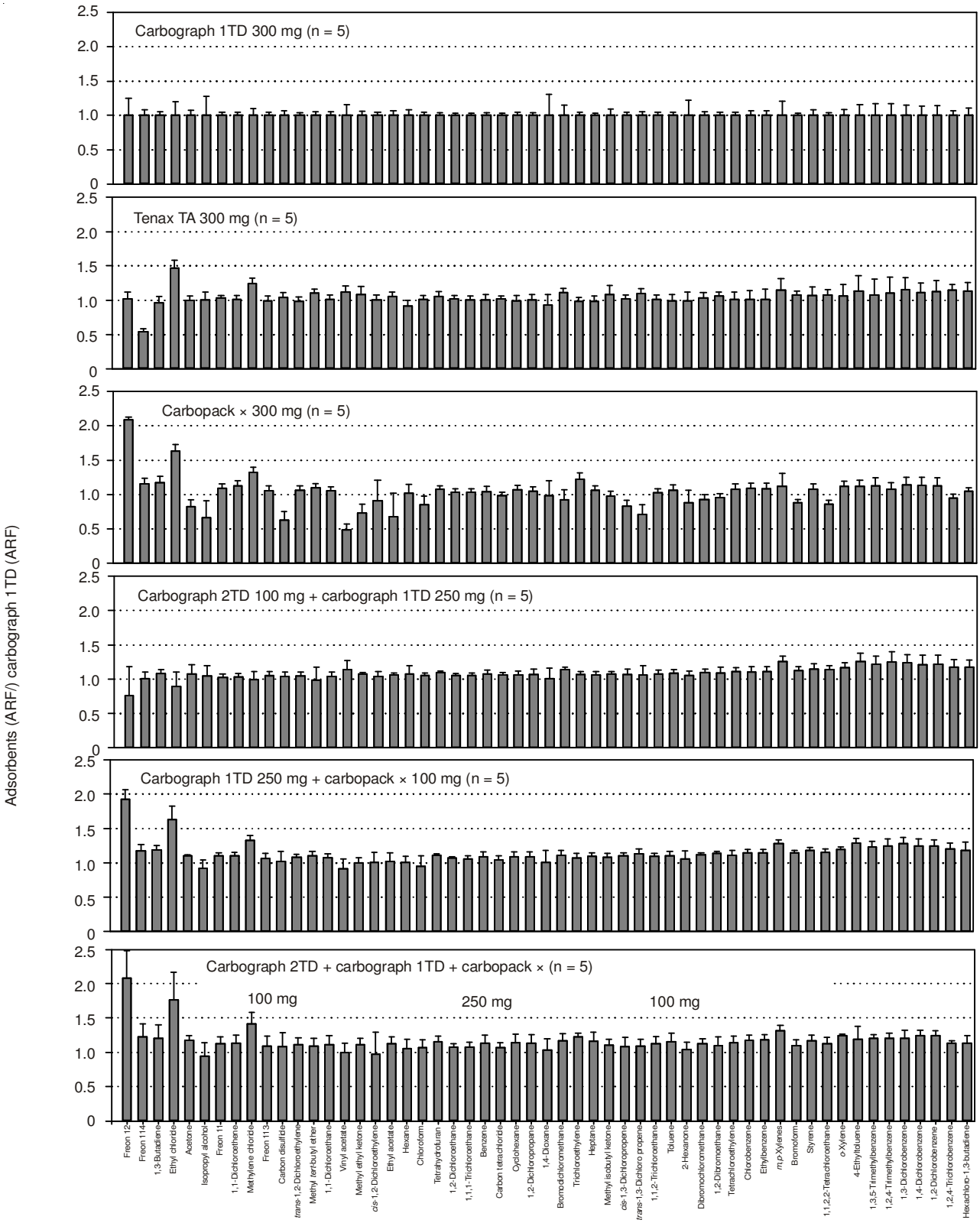
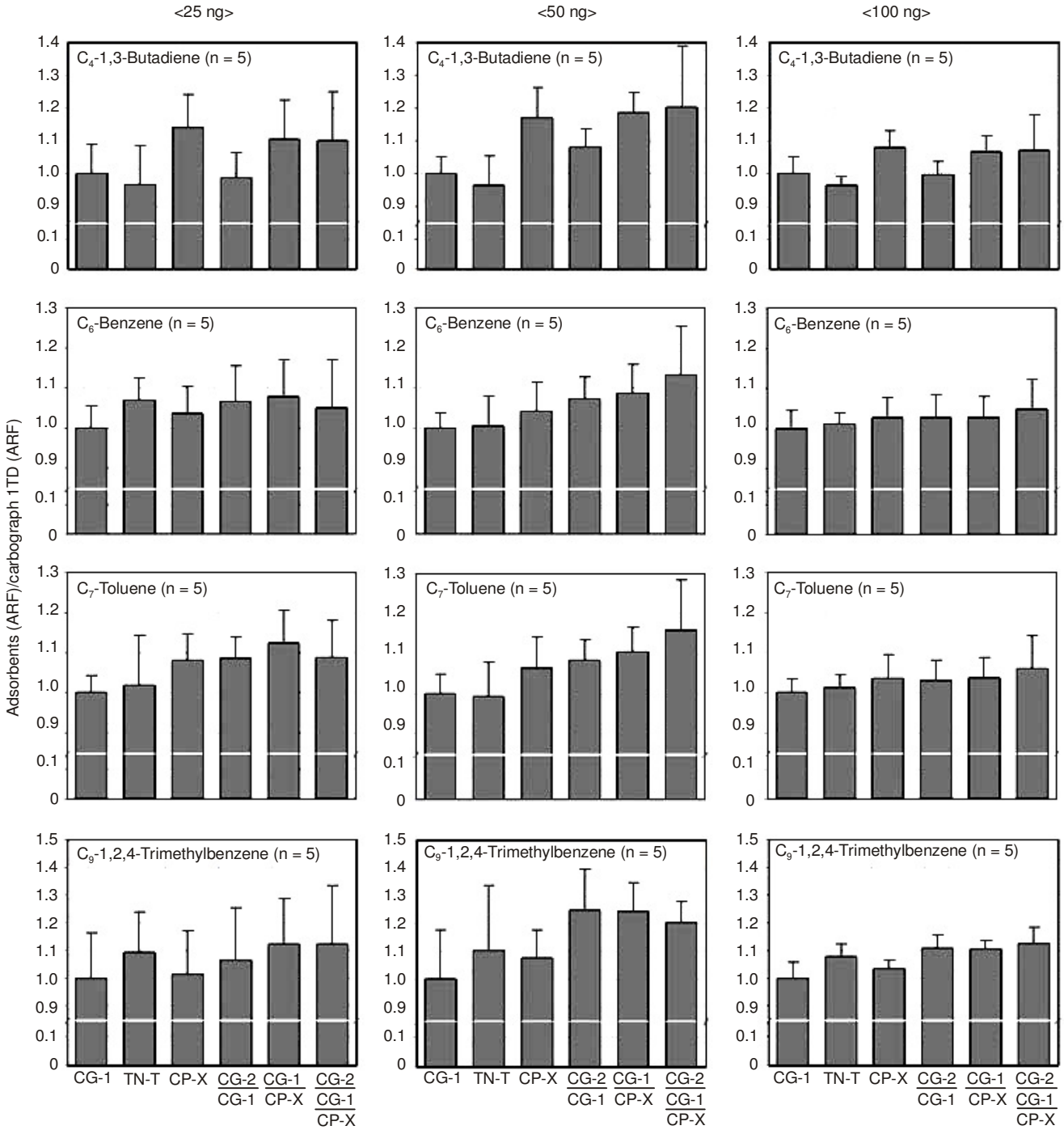


Fig. 4. Comparison of adsorbents efficiency for volatile organic compounds of the standard sample (The impregnated standard gas mixture having 50 ng as benzene amount)

single combination of Carbopack X is not effective towards high molecular weight hydrocarbons and some polar volatile organic compounds such as, vinyl acetate, ethyl acetate, methyl ethyl ketone and isopropyl alcohol. In overall for all hydrocarbons the triple combination of adsorbents (Carbograph 2TD + Carbograph 1 TD + Carbopack X) is efficient than the other combinations.

Performance evaluation of selected adsorbents towards homogeneous hydrocarbons: From Fig. 5, it is observed that a C_4 hydrocarbon and important carcinogen *i.e.*, 1,3-butadiene is effectively adsorbed by the Carbopack X and almost 10-20 % higher than other adsorbent combinations. Benzene and toluene are effectively adsorbed by double and triple combinations of the adsorbents. In case of higher molecular weight hydrocarbons like 1,2,4-trimethylbenzene the performance of Tenax TA, double and triple adsorbent combinations are more effective than others. The reason for this may be attributed to the weak nature of Tenax TA and Carbograph 2TD which can effectively desorbs the higher molecular weight hydrocarbons.

Performance evaluation of selected adsorbents towards heterogeneous hydrocarbons: From Fig. 6, it is clear that the performance of Carbopack X is relatively poor towards



TN-T: Tanax TA, CG-1: Carbograph 1TD, CG-2: Carbograph 2TD, CP-X: Carbopack X

Fig. 5. Comparison of adsorbents efficiency for homogeneous hydrocarbons of the standard sample

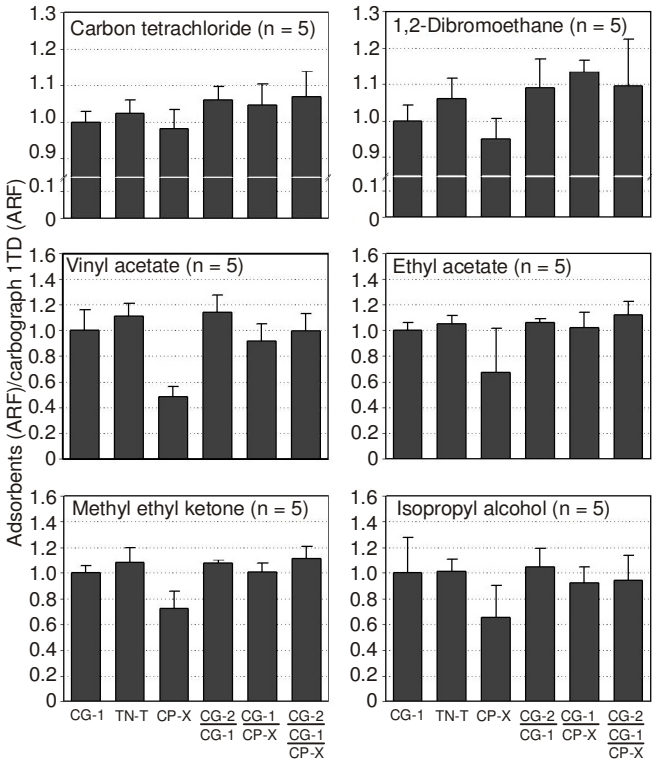


Fig. 6. Comparison of adsorbents efficiency for heterogeneous hydrocarbons of the standard sample (The impregnated standard gas mixture having 50 ng as benzene amount)

the heterogeneous hydrocarbons containing oxygen or halogen atom such as, ethyl acetate, vinyl acetate, methyl ethyl ketone, isopropyl alcohol, carbon tetrachloride and 1,2-dibromoethane than other combinations tested. It indicates that Carbopack X alone shows poor performance towards the polar molecules. The reason for this may be attributed to the strong adsorption and poor desorption of these compounds by Carbopack X. But the performance of Carbopack X can be improved towards these heterogeneous hydrocarbons while combine with other adsorbents.

Linearity evaluation of triple adsorbent tubes: Correlation studies between the standard samples impregnated with standard gas mixture containing 25, 50 and 100 ng of benzene and mass of the triple adsorbent (Carbograph 2TD + Carbograph 1TD + Carbopack X) showed in Fig. 7. From the Fig. 7, it is revealed that the correlation coefficients for hazardous hydrocarbons such as 1,3-butadiene, benzene, toluene and m,p- xylenes are found over 0.98.

Performance evaluation using the real field samples: From the analysis of the standard gas mixture, four high performance adsorbent combinations *i.e.*, Tenax TA, Carbograph 2TD + Carbograph 1TD, Carbograph 1TD + Carbopack X and Carbograph 2TD + Carbograph 1TD + Carbopack X are selected for collecting ambient air samples at the Pohang industrial complex.

The mean (n = 10) concentrations of hydrocarbons found in ambient air samples (field samples) by using the different combinations of adsorbents are shown in Fig. 8. The concentration of benzene, methyl tert-butyl ether and hexane obtained with the Tenax TA is lower than that obtained with the other combination of adsorbents. The measured concentration of

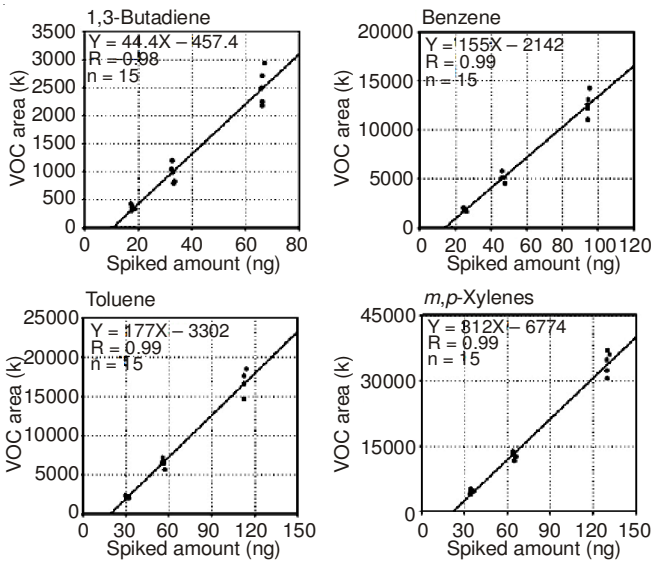


Fig. 7. Linearity evaluations of triple adsorbents

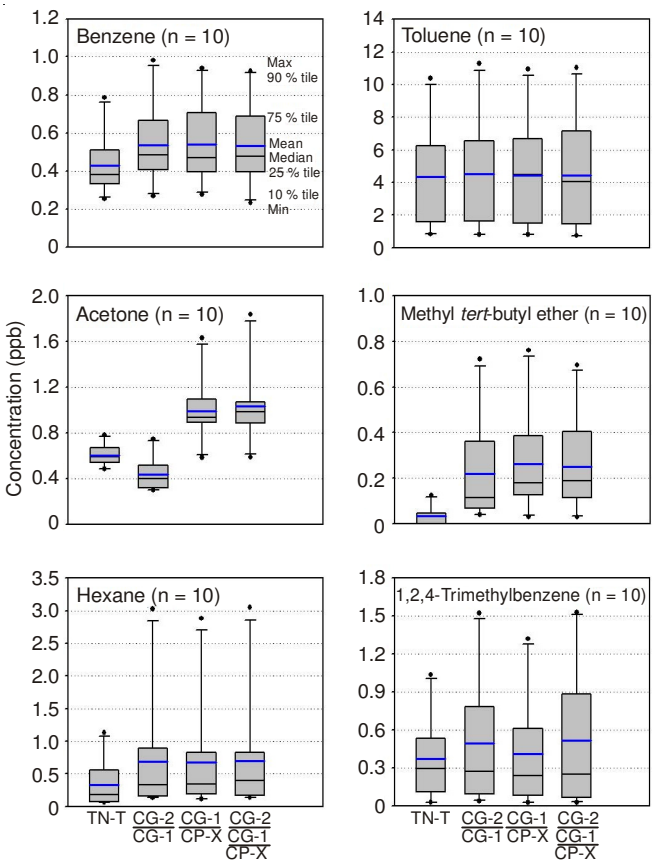


Fig. 8. Concentrations of volatile organic compounds field samples with different combinations of adsorbents

benzene with Tenax TA is almost 20 % lower than the other combinations. The loss of such an important hydrocarbon measured in the ambient air is a defective by using the Tenax TA. In case of toluene almost all the combination of adsorbents gives the similar results. For acetone, the combination with Carbopack X is proved as better adsorbent (s). For high molecular weight hydrocarbon (1,2,4-trimethylbenzene), Carbograph 2TD combination is proved as better than other combinations. From this discussion it is revealed that for hydrocarbons

including C_4-C_{10}, the triple combination of adsorbents (Carbograph 2TD + Carbograph 1TD + Carbopack X) is proved more effective than other combinations tested to collect hydrocarbons from the ambient air.

Conclusion

In this study, we evaluated the sampling performances of adsorbents by simultaneous sampling and analysis of real ambient air samples and standard gas mixture to establish the optimal adsorbent combination for the collection of C_4-C_{10} hydrocarbons.

This study clearly demonstrated the limitations of single adsorbents like Carbopack X and Tenax TA. Carbopack X shows poor performance while using alone especially in case of high molecular weight and polar compounds. But the performance of Carbopack X can be improved with the double and triple adsorbent combinations. Tenax TA shows good performance with standard gas mixture but shows poor performance with real field samples. In real field samples, the compounds such as, benzene, methyl tert-butyl ether and hexane are not effectively adsorbed by Tenax TA alone. Another important prediction from this study is due to weak nature of Carbograph 2TD it can easily desorbs the high molecular weight volatile organic compounds. Due to this nature Carbograph 2TD favors for more usage of strong adsorbents present in inside the adsorbent tube. This study concludes that the combination of triple adsorbents (Carbograph 2TD + Carbograph 1TD + Carbopack X) is proved as best combination than single and double adsorbent combinations.

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