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Development of a test method using a VOC analyzer to measure VOC emission from adhesives for building materials

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Abstract—A volatile organic compound (VOC) analyzer is a portable device to measure the four main aromatic hydrocarbon gases: toluene, ethylbenzene, xylene and styrene. With the VOC analyzer, a semiconductor gas sensor eliminates the need for the carrier gas which is required for conventional gas chromatography. In addition, since the semiconductor gas sensor is supersensitive to gas components, it is not necessary to use a conventional gas concentrator or other complicated equipment. Compared with other measurement methods, the VOC analyzer is useful for measuring toluene, ethylbenzene, xylene and styrene in new buildings because of its ease in obtaining field results and repeating the test. For easy, fast and economic testing of total (TVOC) emission from adhesives used for building materials, we developed a test method using the VOC analyzer and compared its measurement of VOC emissions from building materials such as adhesives, paints and wood-based panels with that of the 20-l chamber method, which is the standardized test method in Korea. There was a good correlation between the TVOC emission concentrations determined by the VOC analyzer and the TVOC emission factor (EF) by the 20-l chamber. Based on this good correlation, the VOC analyzer is expected to gain widespread use in the manufacturing field application where a quick and easy test for VOC emission from adhesives for building materials is required. Furthermore, the VOC analyzer offers the potential to become an easier, faster and more economical technique than the currently used standard methods.

Keywords: VOCs; VOC analyzer; 20-l chamber; adhesives.

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1. INTRODUCTION

During the past decade, researchers have developed various techniques for measuring emissions of volatile organic compounds (VOCs) from building materials. An ASTM standard guide, a guideline from the Commission of the European Communities (CEC, 1992) and a European preliminary standard (ENV 13419 part 13 (CEN, 1998)) have been published for such tests. The emission test techniques for building materials are important to manufacturers, indoor air quality investigators as well as researchers. Such validation is important to quantify the impact of construction products on indoor air quality [1].

Indoor air pollutants mainly include nitrogen oxides (NO_x) and VOCs, which can cause adverse health impacts on occupants [2]. VOCs are primarily composed of BTEX (benzene, toluene, ethylbenzene and *o*-xylene) and halogenated hydrocarbons [3]. Among the numerous VOC compounds, toluene, ethylbenzene, *o*-xylene and styrene were chosen for this study because they are the major VOCs found in indoor environments in different countries [4]. Wolkoff [5] stated that it was necessary to know the nature of the primary and secondary emissions from building products. The primary emissions are free (non-bonded) VOCs and are generally of low molecular weight such as solvent residues, additives and non-reacted raw materials, e.g., monomers. Secondary emissions are chemically- or physically-bonded VOCs and several of these are emitted or formed by different processes under special chemical or physical conditions. Many of the building products that are based on natural raw materials, as opposed to synthetic building products, behave as a secondary emission source and generally continue to emit VOCs. These emissions appear to be partly due to oxidative degradation to lower molecular weight VOCs with low odor thresholds, such as (unsaturated) aldehydes and fatty acids from C_1 to C_{10}, and alcohols like 2-ethylhexanol [6].

The Korean government started controlling indoor air quality in 2004. The regulation prepared by the Ministry of Environment regulates the use of building materials which emit pollutants. The use of materials with TVOC (Total VOC) emission level above 4.0 mg/m^2 h (JIS A 1901, small chamber method) [7] is prohibited. TVOC is calculated between C_6 and C_{16} (see Table 1). Most suppliers and people are concerned about how to reduce pollutants from building materials and how to control indoor air quality [8–10].

In renovated or completely new buildings, the levels of indoor air pollutant emissions from construction and building materials, especially of VOCs, are often several orders of magnitude higher than the VOC levels in existing buildings under normal use [11–14]. Furthermore, the standardization of the emission test and the chemical analysis using the 20-l small chamber method has been conducted under the Ministry of Environment. The 20-l small chamber method was developed in Japan and its performance complies with various ASTM standards (1996, 1997) [15, 16], ECA reports (1989, 1991, 1993, 1995) [17–20] and ENV 13419-1 (1999) [21].

Table 1.
Official toxic VOCs and their characteristics from the American EPA Method TO-14

Compound	Molecular formula	Molecular weight	Boiling point (°C)
Dichlorodifluoromethane	Cl_2CF_2	120.91	−29.8
Methyl chloride	CH_3Cl	50.49	−24.2
1,2-Dichlorotetrafluoroethane	$ClCF_2CF_2Cl$	170.92	3.8
Vinyl chloride	$H_2C{=}CHCl$	62.5	−13.9
Bromomethane	H_3Br	94.94	4
Ethyl chloride	C_2H_5Cl	64.52	12.3
Trichlorofluoromethane	$CFCl_3$	137.37	23.7
1,1-Dichloroethene	$H_2C{=}CCl_2$	96.94	30.0–32.0
Methylene chloride	CH_2Cl_2	84.93	39.8–40.0
1,1,2-Trichlorotrifluoroethane	$ClCF_2CCl_2F$	187.38	47.0–48.0
1,1-Dichloroethane	Cl_2CHCH_3	98.96	57.0–59.0
1,2-Dichloroethane	$ClCH{=}CHCl$	96.94	48.0–60.0
Chloroform	$CHCl_3$	119.38	60.5–61.5
1,2-Dichloroethane	$ClCH_2CH_2Cl$	98.96	83
1,1,1-Trichloroethane	CH_3CCL_3	133.41	74.0–76.0
Benzene	C_6H_6	78.11	80
Carbon tetrachloride	CCl_2	153.82	77
1,2-Dichloropropane	$H_3CH(Cl)CH_2Cl$	112.99	96
Trichloroethylene	$ClCH{=}CCl_2$	131.39	86.9
cis-1,3-Dichloropropene	$ClCH_2CH{=}CHCl$	110.97	105.0–106.0
trans-1,3-Dichloropropene	$ClCH_2CH{=}CHCl$	110.97	97.0–112.0
1,1,2-Trichloroethane	$ClCH_2CHCl_2$	133.41	110.0–115.0
Toluene	$C_6H_5CH_3$	92.14	111
1,2-Dibromoethane	$BrCH_2CH_2Br$	187.87	131.0–132.0
Tetrachloroethylene	$Cl_2C{=}CCl_2$	165.83	121
Chlorobenzene	C_6H_5Cl	112.56	132
Ethylbenzene	$C_6H_5C_2H_5$	106.17	136
m-Xylene	$C_6H_4(CH_3)_2$	106.17	138.0–139.0
p-Xylene	$C_6H_4(CH_3)_2$	106.17	138
Styrene	$C_6H_5CH{=}CH_2$	104.15	145.0–146.0
o-xylene	$C_6H_4(CH_3)_2$	106.17	143.0–145.0
1,1,2,2-Tetrachloroethane	$Cl_2CHCHCl_2$	167.85	147
1,3,5-Trimethylbenzene	$C_6H_3(CH_3)_3$	120.2	162.0–164.0
1,2,4-Trimethylbenzene	$C_6H_3(CH_3)_3$	120.2	168
m-Dichlorobenzene	$C_6H_4Cl_2$	147	172.0–173.0
p-Dichlorobenzene	$C_6H_4Cl_2$	147	173
o-Dichlorobenzene	$C_6H_4Cl_2$	147	179.0–180.0
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	181.45	214
Hexachloro-1,3-butadiene	$Cl_2C{=}CClCCl{=}CCl_2$	260.76	210.0–220.0

Although there are larger chambers, the 20-l chamber with the desiccator method (JIS A 1460) was used in this study because it has been standardized in Korea. The air control system consisted of an air supplying unit, a humidifier, and pumps. A 20-l small chamber was placed in a temperature-controlled climate chamber. Purified air was used for ventilation. A stainless steel seal box was used to prevent

the cut edge effect, which allowed chemical emission only from one side surface of the test piece. When two seal boxes were used, the total surface area was 0.044 m^2 and the loading factor of the sample was 2.2 m^2/m^3 [22, 23].

The VOC analyzer is a portable device to measure the four main aromatic hydrocarbon gases, i.e., toluene, ethylbenzene, xylene and styrene. With the VOC analyzer, a semiconductor gas sensor eliminates the need for the carrier gas which is required for conventional gas chromatography. In addition, since the semiconductor gas sensor is supersensitive to gas components, it is not necessary to use a conventional gas concentrator or other complicated apparatuses. A special column is used to separate the four main aromatic hydrocarbon gases. A high resolution semiconductor sensor is used to detect the separated gases. This special column and high resolution semiconductor sensor were invented by Abilit (Japan) which manufactures the VOC analyzer. The principle of this system is similar to GC/MS and its use for VOC measurement in new buildings is more practical than other measurement methods because it is easy to obtain field results and to repeat the test. In addition, we can control the harmful emission of gaseous products because the analyzer can measure VOCs during the manufacturing of adhesives, paints, furniture and building materials. The VOC analyzer and its structure are shown in Fig. 1.

In this study, we developed a simple test method for the measurement of VOC emissions from building materials using the VOC analyzer. Furthermore, to evaluate the accuracy of the VOC analyzer we compared the results obtained by the VOC analyzer with those from the 20-l small chamber method.

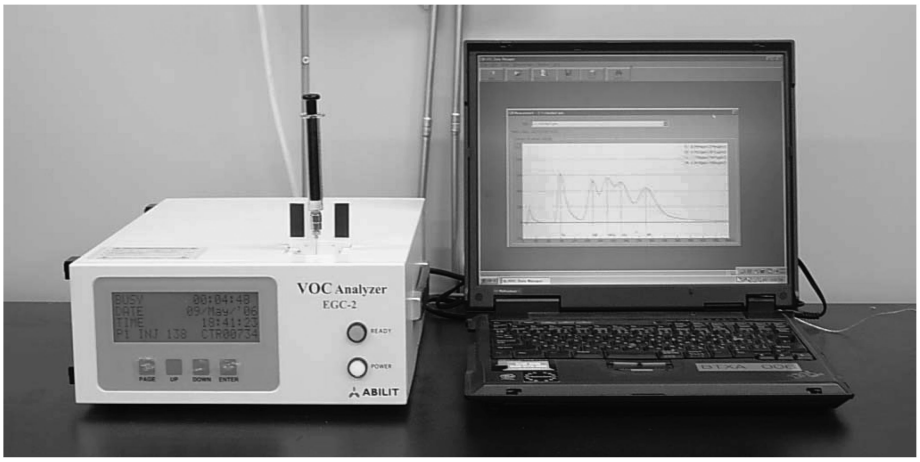
2. EXPERIMENTAL

2.1. Materials

Four commercial adhesives that are extensively used in building materials in new apartment interiors and renovations in Korea were evaluated in this study: chloroprene (for wood, plastic, metal), acrylic resin (for ceramic tile), epoxy resin (two-component type adhesive for wood flooring) and urea-formaldehyde resin (for wood-based composites). Chloroprene and acrylic resin were expected to have higher VOC emissions than the other two adhesives because of their high solvent contents.

2.2. VOC analyzer

To prepare the samples for the VOC analyzer, 1.2 g of adhesives was coated onto aluminum foils, and then cured at 40°C for 60 min in a drying oven. The cured sample was cut and placed in a 3-l polyester bag through a hole in the top of the bag. The bag was purged 3 times with N_2 gas, and then filled with N_2 gas by pulling up the plunger. For the blank control, an empty bag with N_2 gas was prepared. The



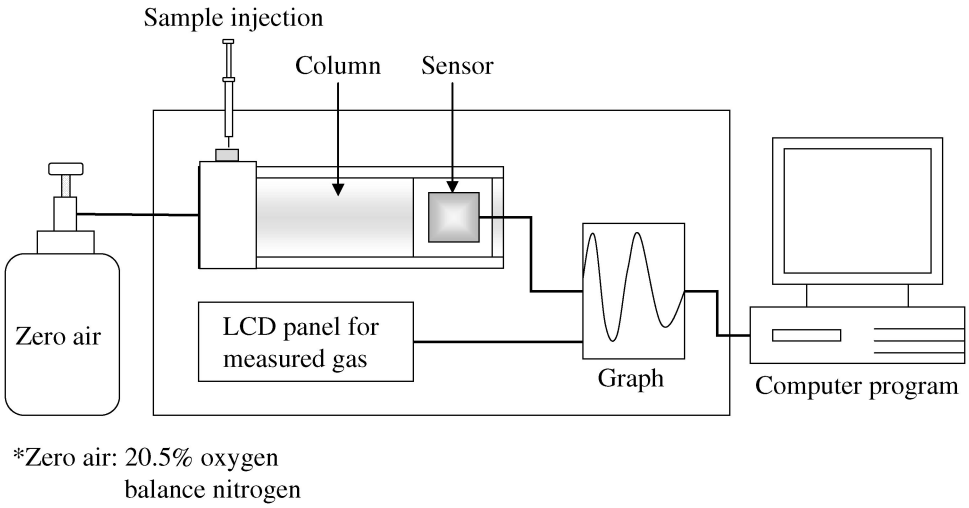


Figure 1. Schematic diagram of the VOC analyzer.

gases for the VOC analyzer were collected from the 3-l polyester bag in a gas-tight (0.5 ml) manner at the required time, placed into the VOC analyzer and analyzed. This process is shown in Fig. 2.

The measurement procedure comprised three steps. First, the gas tight with the product was inserted into the 3-l polyester bag. Then, the plunger was slowly pulled, pushed in again, and pulled out for the second time before the syringe was removed from the polyester bag. If the top of the syringe was wet, it was wiped dry with a tissue. A dedicated needle was attached and 0.5 ml (1/2 calibration) of the sampled gas was ejected by pushing the plunger. The remaining gas was injected into the inlet on the main unit of the VOC analyzer, after which the measurement was automatically started.

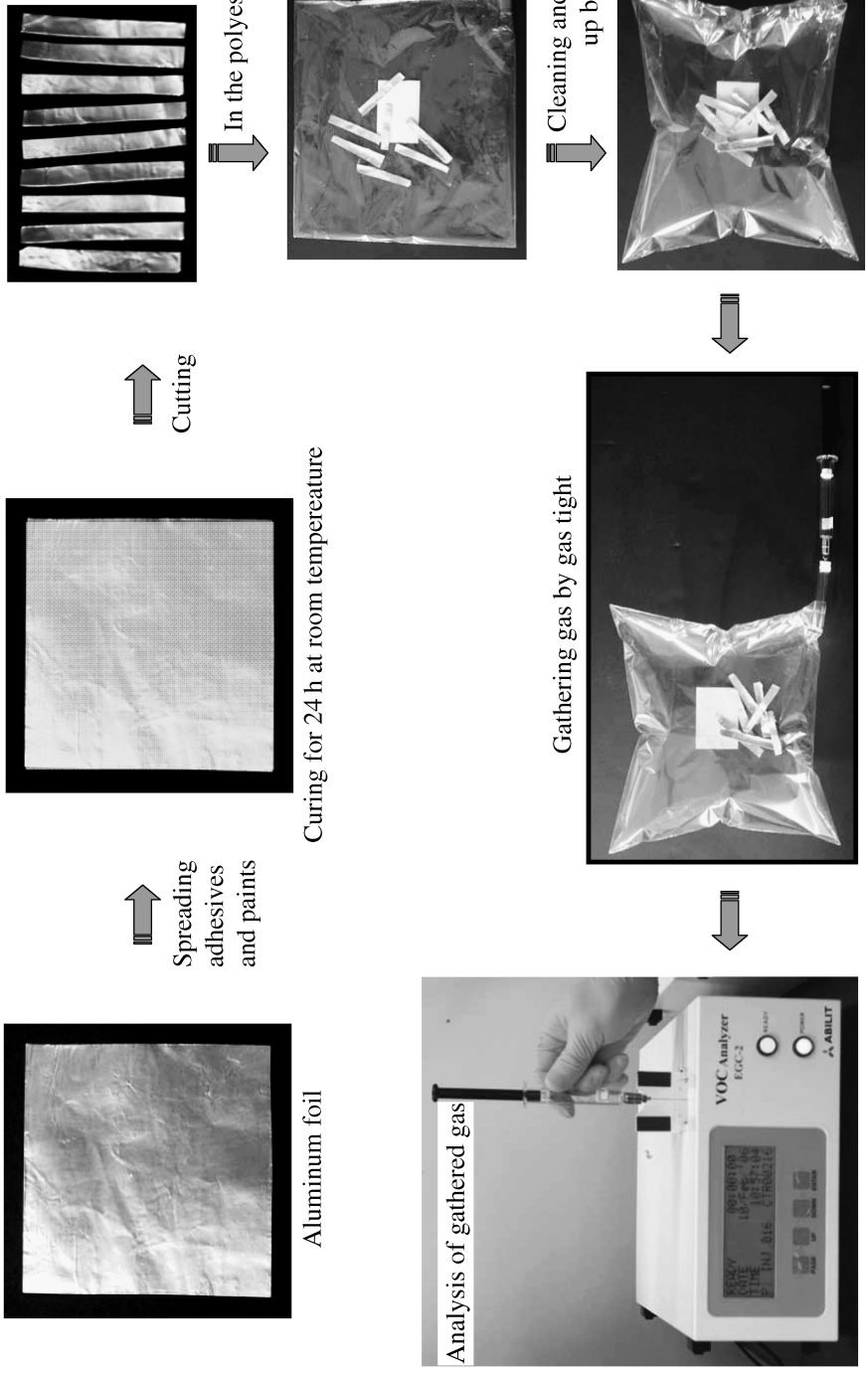


Figure 2. Test method for VOC emissions from adhesives by the VOC analyzer.

2.3. 20-l small chamber method and emission factor

Before setting up the chamber and seal boxes, they were washed with water and baked in an oven at 260°C to eliminate any pollutants from the chamber itself. The 20-l small chamber was supplied with purified and humidified air at a given ventilation rate. The temperature and relative humidity inside the chamber were kept constant.

The following conditions were used for the 20-l small chamber:

Chamber volume:	20 l
Sample size:	0.0432 m^2 (0.147 m × 0.147 m × 2)
Air flow rate:	0.01 m^3/h.
Ventilation rate:	0.5 times/h
Sample loading factor:	2.16 m^2/m^3
Temperature:	25 ± 1°C
Humidity:	50 ± 5°C

The test pieces were sealed with seal boxes, placed in the chamber, and the air inside the chamber was sampled after 12 h. Throughout the tests, the air temperature and relative humidity inside the test chamber were kept constant at 25 ± 1°C and 50 ± 5%, respectively, and ventilated at 0.5 time/h.

Thermal Desorption System (TDS)/GC-MS was used for determining VOCs. The instruments used were as follows.

TDS:		Perkin Elmer ATD400
GC/MS:		HP6890/Agilent5973
Column:		RTX-1 (105 m × 0.32 mm × 3 μm)
Carrier gas:		He (99.99%)
Temperature program:		40°C (5 min) → 70°C (5 min) → 150°C (5 min) → 200°C (5 min) → 220°C (5 min) → 240°C (5 min)
MS conditions:	mode:	EI (Electron ion)
	electron energy:	70 eV
	detection mode:	TIC (scan), m/z: 35/350

In this paper, TVOC was defined according to the conversion of areas of all peaks between C_6 and C_{16} relative to concentrations using the toluene response factor. The limit of detection for the peak area was defined as 10. The sample gas was taken by Tenax-TA (Supelco, USA) 7 days after the sample specimens were installed into the 20-l small chamber, according to the regulation of the Ministry of Environment, Korea. The calculation of the emission factor (EF) is explained in ASTM D5116. Two technical terms are commonly used to describe the rate of emission from indoor materials, EF and ER, which are related as follows:

$$\mathrm{ER} = A(\mathrm{EF}), \tag{1}$$

where: ER = emission rate (mg/h), A = source area (m^2) and EF = emission factor (mg/m^2 h).

3. RESULTS AND DISCUSSION

Figure 3 presents concentrations of the four indicated compounds. For each substance, the concentrations were measured at times corresponding to 0.5, 1, 1.5,

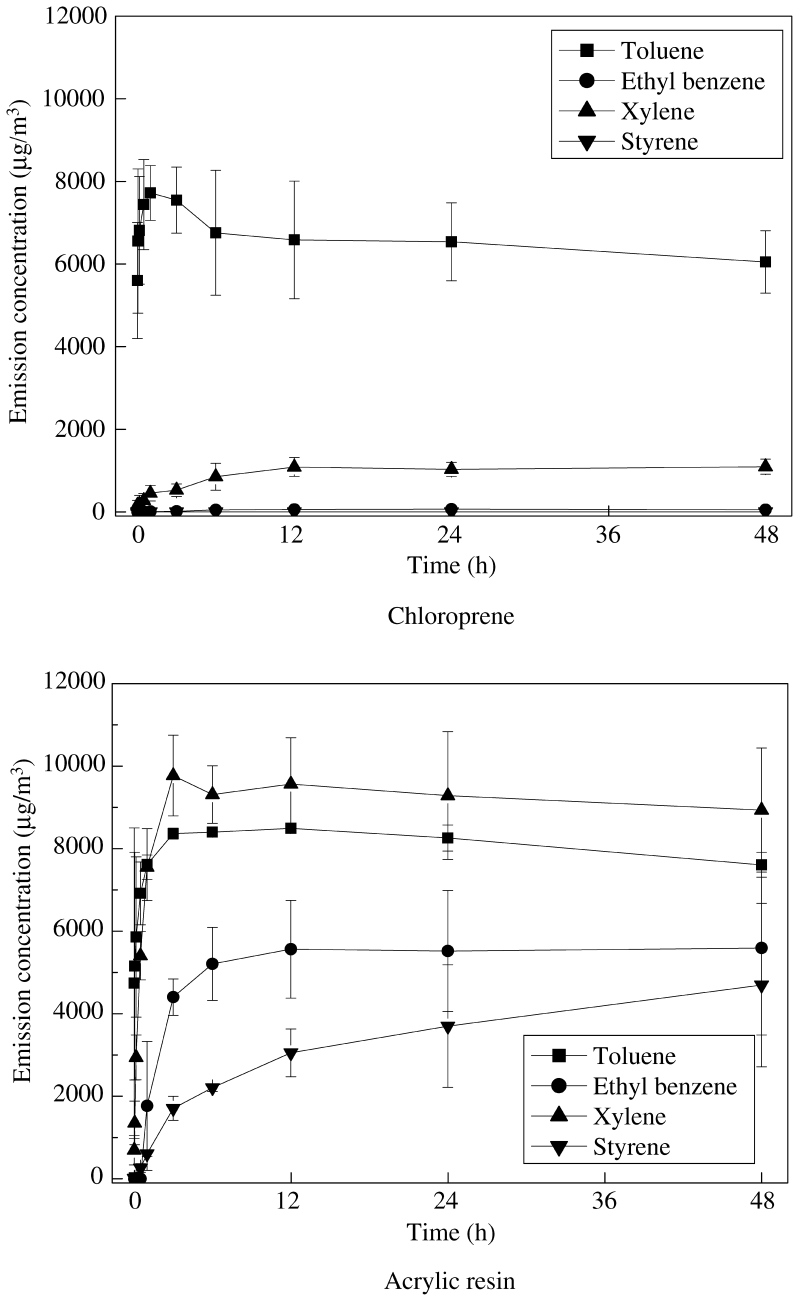


Figure 3. VOC emission concentrations from chloroprene and acrylic adhesive by the VOC analyzer.

2, 3, 6, 12, 24 and 48 h after the start of the test. In the figures, three different phases are observed. In the first phase, the concentration in the 3-l polyester bag increased due to the constant emission of organic compounds and was limited by the given air exchange rate. The first phase began immediately when the material specimens were placed in the 3-l polyester bag and lasted for approximately 3 h. In the second phase, a stabilization and sometimes subsequent decrease of the concentration was observed. After more than 24 h the third phase, a quasistatic equilibrium, was established, depending on the parameters specific for the particular experiment [1]. Figure 3 shows the VOC emission behavior of chloroprene and acrylic adhesive in the 3-l polyester bags. For chloroprene, toluene increased from 5600 $\mu g/m^3$ at the start of the test to 7700 $\mu g/m^3$ after 3 h. Then it decreased and stabilized at 6 h. This tendency was also shown in the other VOC materials such as ethylbenzene, xylene and styrene. After 24 h, the emission concentration reached an optimum concentrate time for VOC by the VOC analyzer. Despite the slight standard deviation, we could determine the characteristic of the VOC emission for chloroprene with the VOC analyzer. For the acrylic resin, this tendency was explored in greater detail. The acrylic resin for the ceramic tiles is not an environmentally friendly adhesive and was expected to have a very high VOC emission. It was a comparable sample for this study because of the high VOC emission of the other adhesives. From Fig. 3, the acrylic resin showed the highest emission of all four VOCs tested. With increasing time, the emission of each VOC increased to a final maximum concentration at 24 h, as in the case of chloroprene. Following are the levels at 24 h: toluene, 8257 $\mu g/m^3$; ethylbenzene, 5518 $\mu g/m^3$; xylene, 9285 $\mu g/m^3$; styrene, 1484 $\mu g/m^3$. Although the styrene level was still increasing, the maximum emission concentration in the 3-l polyester bag was reached at 24 h. In contrast with chloroprene, xylene was the highest emission VOC.

Two-component type of epoxy resin for wood flooring and urea-formaldehyde resin for wood-based composites are shown in Fig. 4. These adhesives emitted very low levels of toluene, ethylbenzene, xylene and styrene. Initially, even toluene was emitted at a maximum of 300 $\mu g/m^3$ while the others were under 30 $\mu g/m^3$. At 24 h, the emission levels for urea-formaldehyde resin were as follows: toluene, 209 $\mu g/m^3$; ethylbenzene, 1 $\mu g/m^3$; xylene, 31 $\mu g/m^3$; and styrene was not detected. Furthermore, the VOC emissions were undetectable for epoxy resin. Because epoxy resin and urea-formaldehyde resin both are thermosetting adhesives, there was no VOC emission after thermal curing. However, in the case of wood-based panels which are bonded with urea-formaldehyde resin, Koontz and Hoag [24] reported that unfinished particleboard and medium density fiberboard from North America emitted many VOCs in addition to formaldehyde, and often at higher concentrations than formaldehyde. Major VOCs reported were (in approximate order of amounts emitted): acetone > hexanal > pentanal > benzaldehyde > pentanol > heptanal > pinenes > nonanal > octanol. In this experiment, it was found that the particleboard specimens emitted hexanal, pinenes, pentanal, nonanal, heptanal and octanol. These

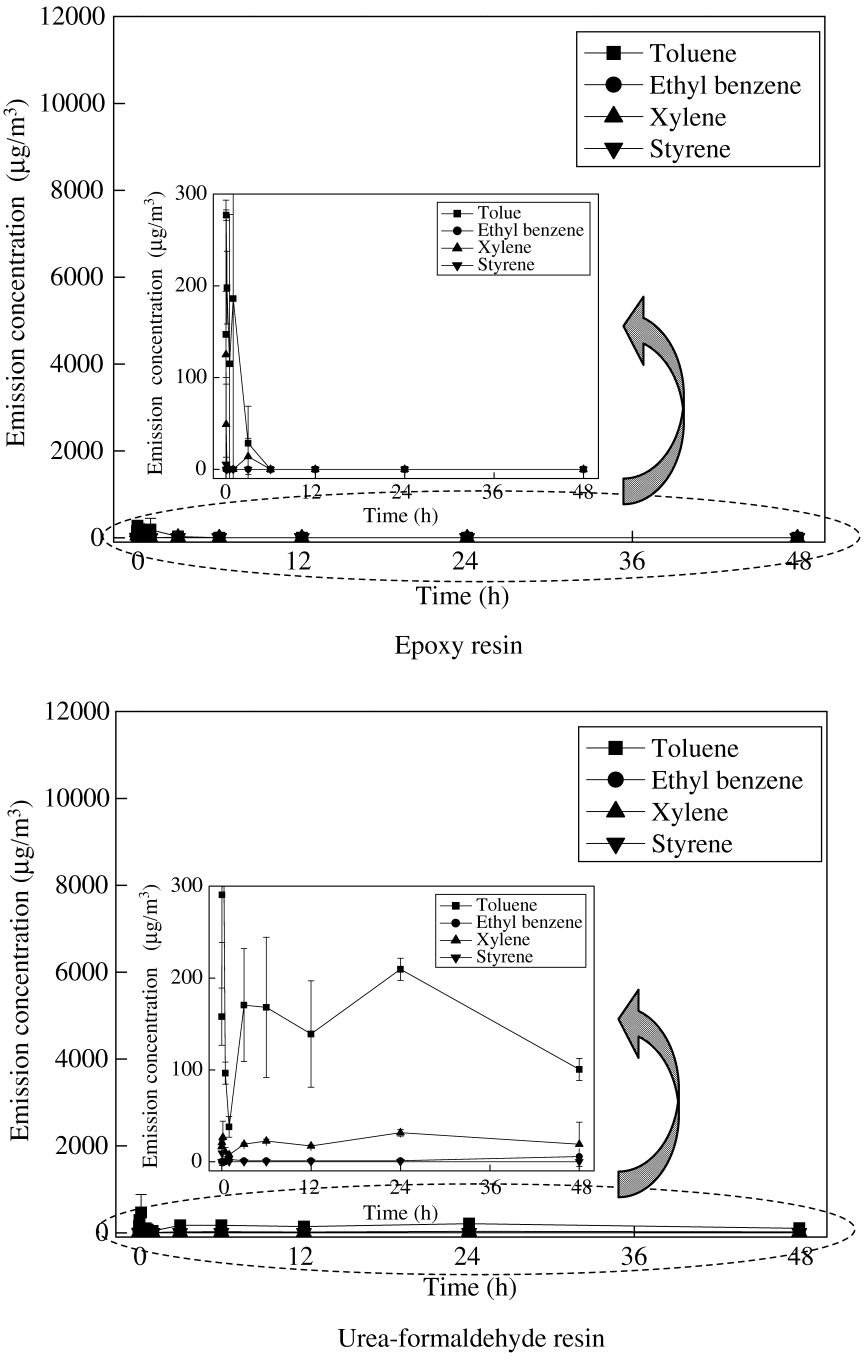


Figure 4. VOC emission concentrations from epoxy resin and urea-formaldehyde resin by the VOC analyzer.

substances rather come from hydrolysis of wood components, and not from the reaction of wood with the urea-formaldehyde resin.

The four VOCs from the adhesives, which were detected by the VOC analyzer, are shown in Fig. 5. All four VOCs were emitted at higher levels from acrylic resin than from any of the other adhesives, and an especially high xylene content of almost 10 000 μg/m^3 was detected. In the case of chloroprene, a high emission

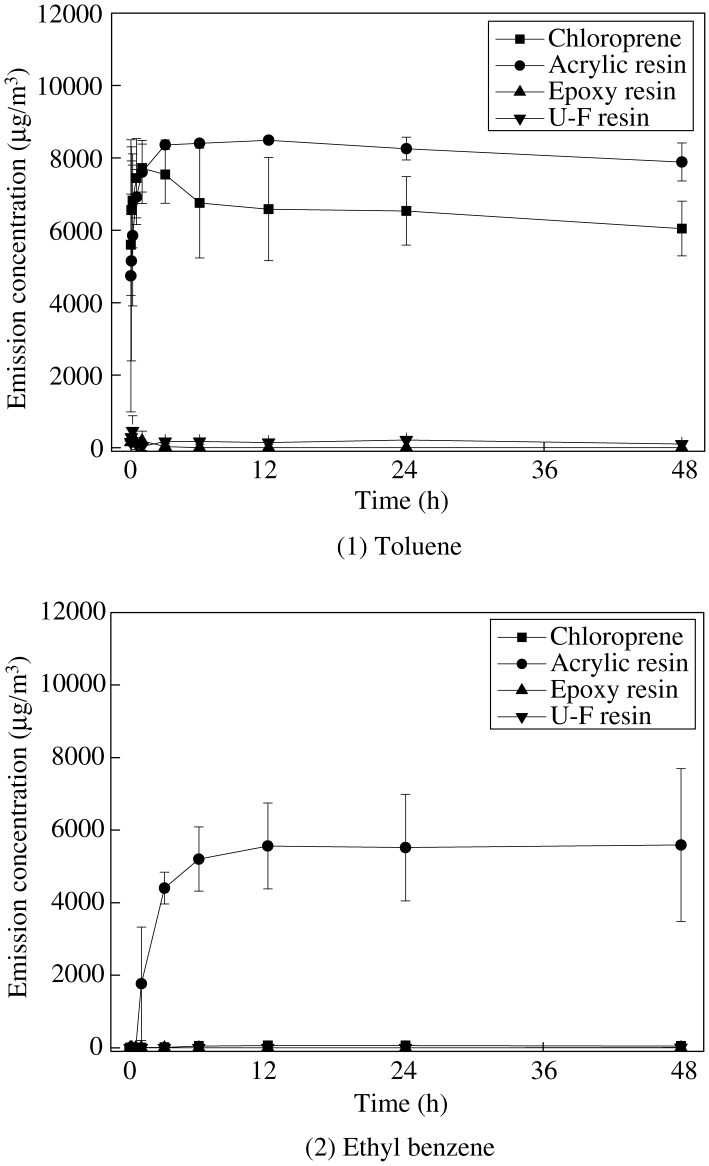
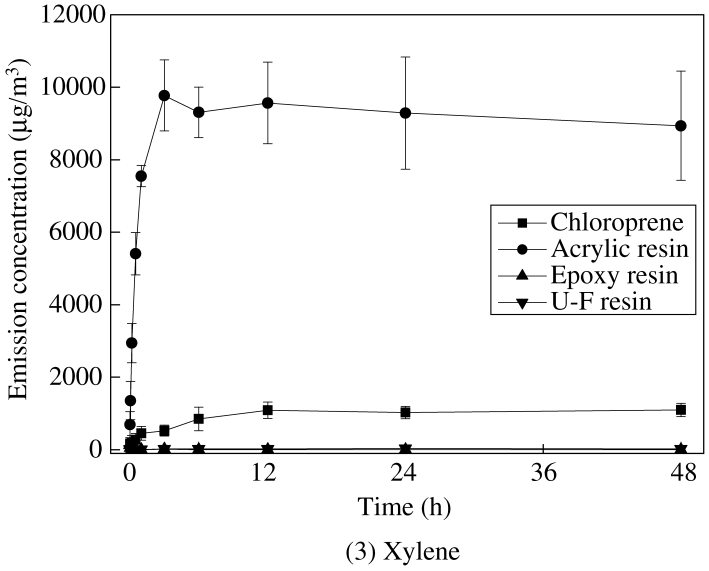
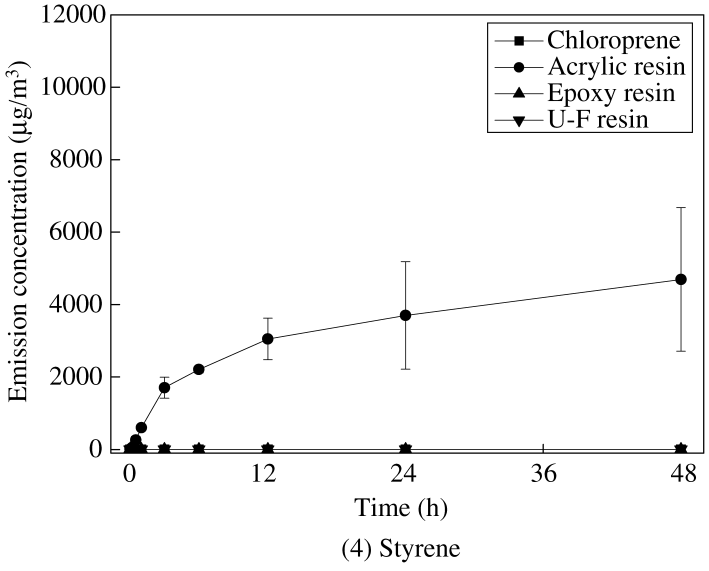


Figure 5. VOC emission concentrations (of toluene, ethylbenzene, xylene and styrene) from all the adhesives as determined by the VOC analyzer.



(3) Xylene



(4) Styrene

Figure 5. Continued.

concentration of toluene was shown at about 8000 μg/m^3. At 24 h, all four VOCs showed optimum emission concentration time for the VOC analyzer.

In Korea, the Ministry of Environment provides guidelines for the VOC emissions from building materials as total VOC (TVOC). Even natural VOCs from wood are considered to be harmful and are included in the TVOC calculation. Consequently, it is necessary to consider natural VOCs when reassessing the regulations governing VOC emissions from building materials. However, in the results from the VOC

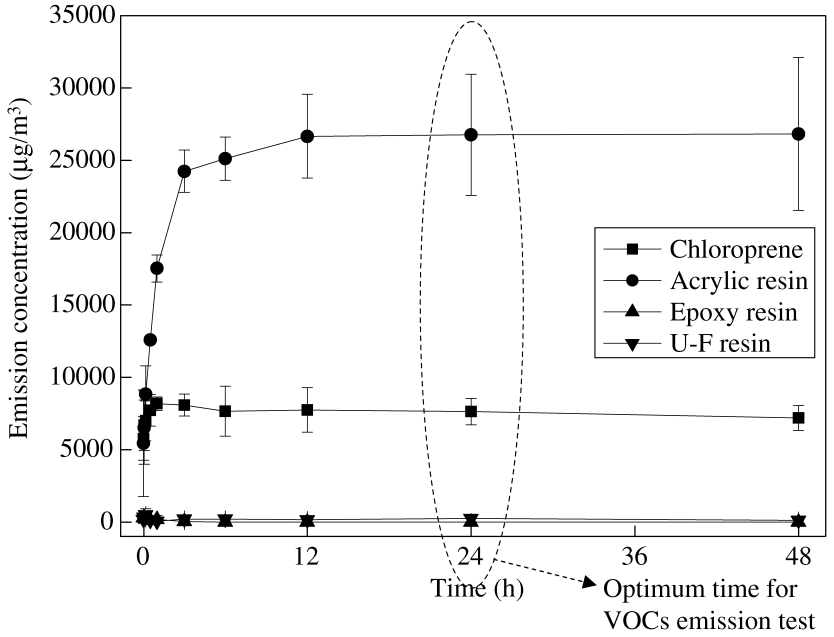


Figure 6. TVOC emission concentrations from all the adhesives as determined by the VOC analyzer.

analyzer, TVOC was defined as the total sum of the four detected VOCs, as shown in Fig. 6. Over the initial 12 h of the test, the TVOC emission concentration increased and reached a maximum at 24 h. As mentioned above, the 24 h period was determined to be the optimum time for VOC emission concentration by the VOC analyzer. TVOC emission was 26 761 μg/m^3 for acryl resin and 7630 μg/m^3 for chloroprene, while the levels were very low for epoxy resin and urea-formaldehyde resin.

To compare with the standard method, we tested TVOC emission with the 20-l chamber method. TVOC EFs for all adhesives, between C_6 and C_{16}, are shown in Fig. 7. The emission gases were collected after 1, 3, 5 and 7 days after the adhesive samples were placed in the small chamber. The results after 1 day, determined from equation (1) and presented in Table 2, were as follows: chloroprene, 8.05 mg/m^2 h; acrylic resin, 3.31 mg/m^2 h; epoxy resin, 0.28 mg/m^2 h; and urea-formaldehyde resin, 0.47 mg/m^2 h. All VOCs from all the adhesives by the 20-l chamber system are shown in Table 2. Although EFs by the 20-l chamber were different from the emission concentrations by the VOC analyzer, these differences were reduced with increasing time. The air in the 20-l chamber was completely exchanged every 2 h. This continuous air exchange in the 20-l chamber test decreased the EF value with increasing time. However, there was a correlation between the results of the VOC analyzer and the 20-l chamber.

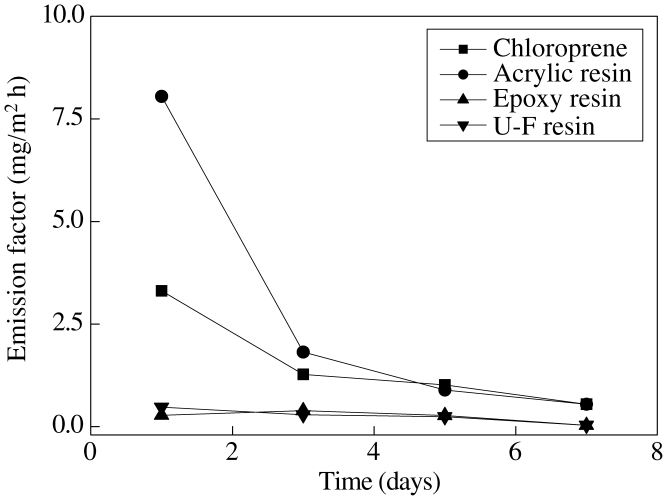


Figure 7. TVOC emission factors from all the adhesives as determined by the 20-l chamber.

4. CONCLUSIONS

VOC emissions from adhesives can adversely affect the indoor air quality. In Korea, standard test methods have been developed to determine VOC emissions from building products and the Ministry of Environment regulates the use of building materials that generate pollutant emissions because the Korean Government has been controlling the indoor air quality since 2004. In the Korean Government regulations, TVOC is calculated between C_6 and C_{16}. The 20-l small chamber method was developed in Japan and its performance has been internationally recognized as being in compliance with ASTM, ECA reports and ENV 13419-1. However, the 20-l chamber method is expensive and time consuming to analyze TVOC EFs from adhesives or building materials. Therefore, in the present study the performance of the VOC analyzer was evaluated and the results showed the newly developed system to be an easy, fast and economical method for determining TVOC emission levels, especially in the field of manufacturing.

Although the 20-l chamber method is the standard VOC emission test in Korea, we have developed an easier, faster and more economical test which is also portable. The results of TVOC emission concentration and TVOC EF confirmed the good correlation between the results of the VOC analyzer and the 20-l chamber for the adhesives, as shown in Fig. 8. TVOC emission concentration by the VOC analyzer was directly proportional to the TVOC EF by the 20-l chamber. Based on this good correlation, the VOC analyzer is expected to gain widespread use in the manufacturing field, where a quick and easy test for VOC emission is required. Due to its good correlation with the standardized, 20-l chamber, TVOC emission levels, the VOC analyzer can be successfully applied to the measurement of TVOC emission from adhesives for building materials. With further refinement, the quantitative analysis of TVOC emission by the VOC analyzer will become

Table 2.
VOC emission levels (mg/m^3) from all four adhesives by the 20-l chamber method after different times (1, 3, 5 and 7 days)

	VOC Compound															
	Chloroprene				Acrylic resin				Epoxy resin				Urea-formaldehyde resin			
	1	3	5	7	1	3	5	7	1	3	5	7	1	3	5	7
1,1,1-Trichloroethane	0.0000	0.0000	0.0000	0.0000	0.0004	0.0002	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Benzene	0.0084	0.0050	0.0076	0.0002	0.0078	0.0077	0.0074	0.0001	0.0071	0.0089	0.0058	0.0001	0.0105	0.0085	0.0072	0.0001
Trichloroethylene	0.0001	0.0001	0.0001	0.0000	0.0003	0.0001	0.0001	0.0000	0.0005	0.0001	0.0007	0.0000	0.0002	0.0003	0.0002	0.0000
Toluene	0.1588	0.0124	0.0151	0.0009	2.1517	1.1319	0.3541	0.1857	0.0296	0.0286	0.0206	0.0013	0.0182	0.0333	0.0202	0.0006
Tetrachloroethylene	0.0009	0.0008	0.0022	0.0000	0.0027	0.0014	0.0009	0.0000	0.0042	0.0014	0.0041	0.0000	0.0033	0.0025	0.0027	0.0000
Chlorobenzene	0.0005	0.0003	0.0005	0.0000	0.0006	0.0004	0.0008	0.0000	0.0006	0.0006	0.0007	0.0000	0.0005	0.0006	0.0006	0.0000
Ethylbenzene	0.0001	0.0001	0.0001	0.0001	0.0285	0.0070	0.0023	0.0015	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001
p-Xylene	0.0002	0.0002	0.0002	0.0002	0.0582	0.0151	0.0053	0.0031	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002
Styrene	0.0004	0.0003	0.0003	0.0000	0.0003	0.0004	0.0003	0.0000	0.0004	0.0004	0.0003	0.0000	0.0017	0.0004	0.0003	0.0000
o-Xylene	0.0001	0.0001	0.0001	0.0001	0.0293	0.0000	0.0042	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000
1,2-Dichlorobenzene	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
1,2,4-Trichlorobenzene,	0.0005	0.0003	0.0002	0.0001	0.0003	0.0002	0.0002	0.0001	0.0003	0.0002	0.0002	0.0001	0.0003	0.0003	0.0002	0.0001
TVOC (μg/m^3)	4.1401	1.5952	1.2727	0.6796	10.0634	2.2735	1.1179	0.6827	0.3439	0.4866	0.3427	0.0423	0.5894	0.3621	0.3008	0.0417

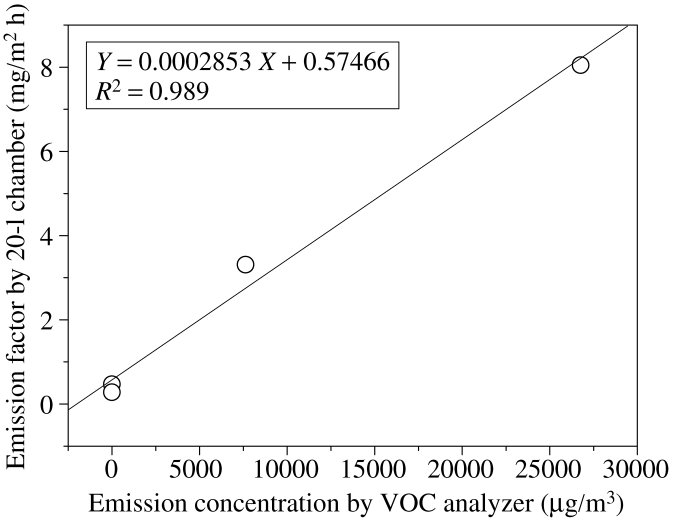


Figure 8. Correlation between TVOC emission concentration by the VOC analyzer and TVOC emission factor by the 20-l chamber.

an easier, faster and more economical technique than the currently used standard methods.

The following summarizes the basic performance and features of the VOC analyzer:

- Identification of the four main aromatic hydrocarbon gases (toluene, ethylbenzene, xylene and styrene)
- Display of gas concentrations in standard units of ppm and μg/m^3
- Precise measurement accuracy with the simplified gas chromatography method
- No carrier gas required
- Not affected by ambient temperature and humidity
- Short standby time of 30 min or less
- Short measurement time of 8 min

Using 3-l polyester bags, we developed a TVOC emission test for adhesives by utilizing the VOC analyzer. There was a good correlation between TVOC emission concentration by the VOC analyzer and TVOC EF by the standardized 20-l chamber method. Furthermore, in the future we will analyze the TVOC emissions from other building materials and paints.

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