

CHARACTERIZATION OF VOC EMISSIONS FROM INTERIOR MATERIALS OF RAILROAD PASSENGER CABIN AND PREPARATION OF ENVIRONMENT-FRIENDLY INTERIOR MATERIAL

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ABSTRACT

The indoor air quality of railroad passenger cabin is often polluted by various pollutants. The pollutants sources of the passenger cabin are the passengers with their belongings, the inflowing outdoor air, and the interior materials like floorings, seats, paints, and adhesives. In this study, we focused on the pollutants emissions from the interior materials, and carried out the characterization of emitted volatile organic compound (VOC) in an environmental chamber. We could find out that a large amount of various VOCs emitted from the surface of interior materials. Especially, toluene and benzene emission was significant in our experiment, and these emissions seemed to affect the indoor air quality of the passenger cabin. To minimize these VOC emissions, we also prepared environment-friendly interior material in this study. We coated the titanium dioxide (TiO₂) on the surface of the interior material to reduce the emission of hazardous organic air pollutants. We had our environmental chambers equipped with UV lamp to investigate the effect of UV irradiation on the VOC emissions from TiO₂ coated interior material. We monitored the VOC emissions over time with and without UV irradiation in our environmental chambers. We could observe that the interior materials coated with TiO₂ emitted less VOC than not coated ones in the absence of UV irradiation, which is probably due to the adsorption of VOC on TiO₂. Under UV irradiation condition, VOC levels in the environmental chamber with TiO₂ coated interior materials were lower because of the photocatalytic degradation of VOC. We also coated the interior materials with an antibacterial material to suppress the growing of bacteria on the interior material. We could observe that the coating with a very small amount of antibacterial material on the interior material could prevent the growing of bacteria by 99%. By using TiO₂ and antibacterial material, we could prepare an environment-friendly interior material successfully.

KEYWORDS

VOC, Indoor air quality, Interior material, Photocatalyst, Antibacterial material

INTRODUCTION

The sick house syndrome or new house syndrome has been notorious because they threaten the health of human being. Similarly, the new car syndrome is also gaining wide attention nowadays. Tremendous amount of various hazardous air pollutants are emitted from the interior materials, adhesives, sealants, and paints of cars. These pollutants can be very dangerous for the passenger. In case of railroad passenger cabin, the situation is quite similar to that of cars because largely similar materials are used for the manufacturing of the passenger cabin.

In Korea, the platform and the waiting room of the railroad stations have been regulated by 'Act on the Indoor Air Quality Management of Public Places' in Korea, since 2003. However, the railroad passenger cabin, where the passengers spend more time, has been excluded from this law. But, due to the drastic increase in the public interest on the indoor air quality of passenger cabin, a new guideline for the regulation of the indoor air quality for the passenger cabin was prepared recently. According to this act, the concentrations of particulate matters and carbon dioxide in buses, subways, and trains are

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under regulation. However, unfortunately, the VOC level control was excluded from the act after a long argue between the Korean government and the transportation manufacturers because there is no technical way to control the VOC levels as for now.

In this study, we focused on the pollutants emissions from the interior materials, and carried out the characterization of emitted VOC in an environmental chamber. Furthermore, we prepared environment-friendly interior material for the minimization of VOC emissions. Furthermore, we also applied antibiotic materials to prevent the growth of microorganisms on the interior materials. The experimental setup and the obtained results will be described in this study.

EXPERIMENTAL

Materials

Commercial seat cover and flooring materials of railroad passenger cabin were purchased from the interior material makers. The purchased materials are currently applied to the railroad passenger cabin in Korea. The seat cover was made of polyester (double russel and moquette), and the flooring was done of polyvinyl chloride. All samples were completely sealed after being manufactured to prevent the natural emissions of VOCs. The samples were used for our experiments immediately after purchase. Titanium dioxide (TiO_2) was coated on the surface of the materials in order to prepare interior material with low VOCs emission (Figure 1 left). The weight percentage of TiO_2 was 0, 0.5, 1.0, and 2.0 %, respectively. We prepared another interior material with zeolite to prevent the growth of microorganism (Figure 1 right). The weight percentage of zeolite antibiotic agent was 0, 0.5, 1.0, 2.0, and 5.0 %.

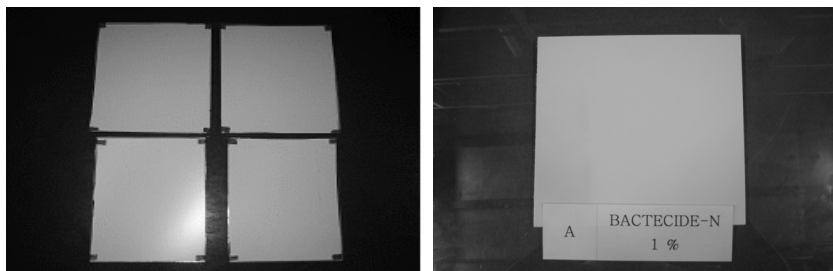


Figure 1. Prepared interior material coated with TiO_2 (left) and zeolite antibiotic agent (right).

Characterization of VOC Emission

A VOCs emission testing system for the measurements of emitted VOCs was devised as presented in Figure 2. A 1.0 m^3 ($1.0 \text{ m} \times 1.0 \text{ m} \times 1.0 \text{ m}$) stainless steel environmental test chamber was used. Four 88 liter ($0.4 \text{ m} \times 0.4 \text{ m} \times 0.55 \text{ m}$) mini-chambers were placed in the environmental chamber. The mini-chambers were sealed, and laminar airflow was generated by a fan placed on their bottoms. The air was supplied using a compressor after being purified by filtration (a HEPA filter and an activated carbon filter) and photocatalysis. Humidified air was supplied by bubbling the air through deionized water. Dry and humidified air was mixed before supply, and the humidity was controlled by changing the mixing ratio.

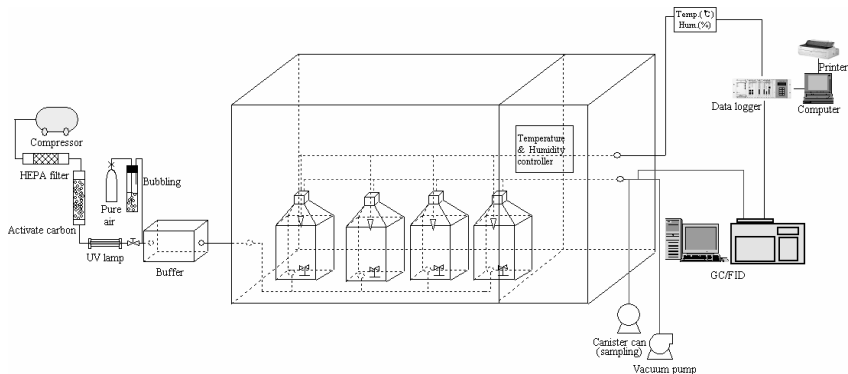


Figure 2. Schematic diagram of VOCs emission experimental setup.

The VOCs levels of the mini-chamber blanks were monitored to ensure the cleanliness of the chambers, before testing of each sample. Samples were clipped with stainless steel plate holders. The total surface area of sample was $0.332 \text{ m} \times 0.386 \text{ m} \times 10 \text{ ea}$ (1.28 m^2). The airflow rate of the supplied air was 1.4 l min^{-1} . The air temperature and relative humidity of the mini-chambers were fixed at $24 \pm 2 \text{ }^\circ\text{C}$ and $50 \pm 5 \%$, respectively. The product loading was $1.455 \text{ m}^2 \text{ m}^{-3}$. The air of the mini-chambers was sampled via sampling tubing, and collected to a Canister can (6 liter, Entech Co.).

UV Irradiation Chamber

We equipped a 36 W mercury lamp in the mini-chamber to irradiate UV as shown in Figure 3. In this experiment, we placed two $36 \times 42 \text{ cm}$ panels and two $32 \times 42 \text{ cm}$ panels parallel to the lamp to maximize the UV absorption. The VOC emissions with or without UV irradiation was investigated.

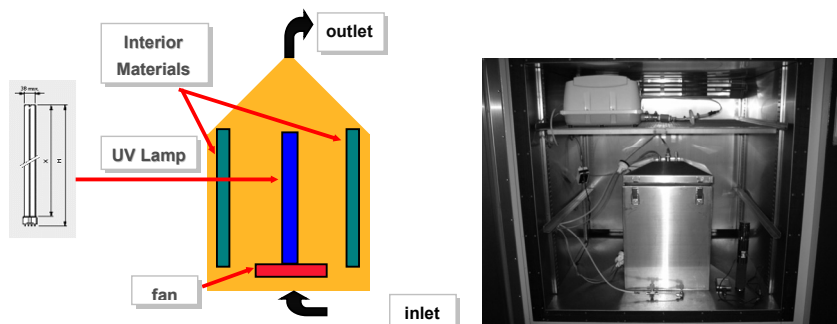


Figure 3. Experimental setup of the UV irradiation chamber for the evaluation of the interior materials.

Analysis

VOCs levels were measured using TO-14 method of US Environmental Protection Agency (US EPA). Sample collected in the canister can was analyzed by gas chromatography (HP 6890N) equipped with a HP-1 column ($90 \text{ m} \times 0.32 \text{ mm} \times 5 \text{ }\mu\text{m}$) and a mass spectrometric detector (HP 5973). Duplicate injections were made for each sample. The concentrations of VOCs were determined for all the samples and were reported as parts per billion (ppb) on a volume basis. QA/QC was checked before our analysis.

As for the antibiotic performance of the interior material, we followed the test procedure of Japanese Industrial Standard (JIS Z 2801-2000) method. We observed the number change of microorganism for 24 hours. The standard film was 400 POLY-BAG (Stomacher). The testing condition was 35 ± 1 °C in temperature, and 90 % in relative humidity. *Escherichia coli* ATCC 8739 were used as the microorganism.

RESULTS AND DISCUSSION

VOCs Emissions from Seat Cover

VOCs emissions from the seat cover of Mugunghwa-ho Express (Figure 4a) and Saemaeul-ho Express (Figure 4b) passenger cabin were investigated in the environmental test chamber. The results showed that dichloropropene, trichloroethane, toluene, ethylbenzene, xylene, styrene, trimethylbenzene, and some infinitesimal compounds were detected. The similar kinds and levels of VOCs were emitted from the seat cover of Mugunghwa-ho Express and that of Saemaeul-ho Express. The levels of *trans*-1,3-dichloropropene, 1,1,2-trichloroethane, and toluene were high, and the concentration profiles of them were presented in Figure 3. The levels rapidly decreased over time under our constantly ventilated condition, which is a general trend observed in many previous studies (Schaeffer et al. 1996, Wolkoff 1998, Yu and Crump 1998). The emission decays of these VOCs were independent on the kinds of VOCs, meaning the VOCs emission characteristics are independent on the chemical characteristics of each VOC species.

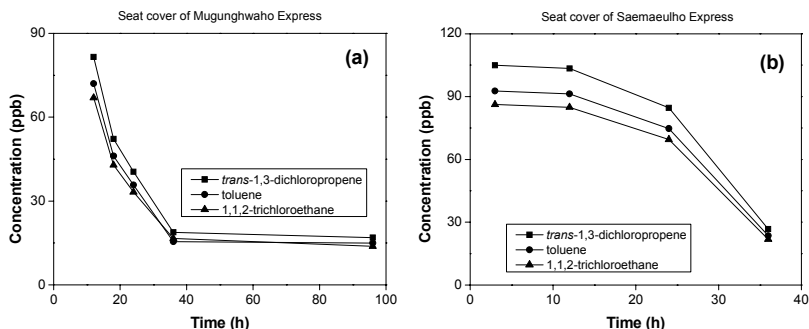


Figure 4. VOCs emission from the seat cover of (a) Mugunghwa-ho Express and (b) Saemaeul-ho Express.

The potential toxicity and hazard of halogenated VOCs have been serious concern for health. In our experiment, some halogenated compounds (e.g., dichloropropene, trichloroethane, etc.) were detected during the VOCs analysis. Considering that the seat covers were made of polyester, which does not contain any halogen compounds, the halogen sources of VOCs are maybe chemical additives (e.g., dyes, adhesives, solvents, etc.) added during the manufacturing processes of the products. They seemed to contribute to the formation of halogenated VOCs. Therefore, the use of chemical additives should be minimized in the manufacturing process.

VOCs Emissions from Flooring Material

VOCs emissions from the flooring of Mugunghwa-ho Express (Figure 5a) and Saemaeul-ho Express (Figure 5b) passenger cabin in the environmental test chamber were investigated. The results showed that dichloroethylene, benzene, dichloropropene, trichloroethane, toluene, ethylbenzene, xylene, styrene, trimethylbenzene, trimethylbenzene, vinyl chloride, and some infinitesimal compounds were

detected. To the same case with the seat cover, the VOCs levels of *trans*-1,3-dichloropropene, 1,1,2-trichloroethane, and toluene were high, while those of other compounds were at around the detection limit. The concentration profiles of these three VOCs species were presented in Figure 5. The concentrations decreased over time under the same conditions with Figure 4.

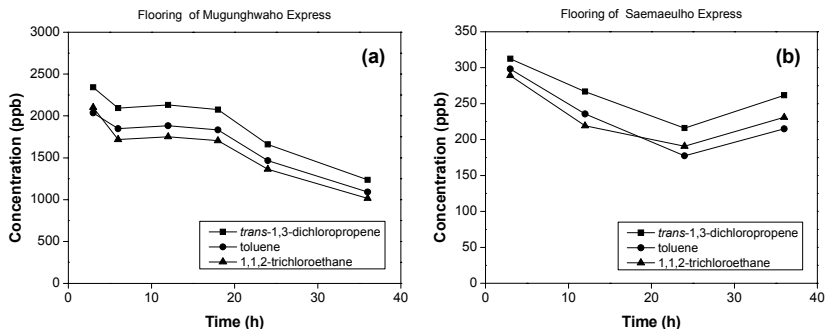


Figure 5. VOCs emission from the flooring of (a) Mugunghwa-ho Express and (b) Saemaaul-ho Express.

Benzene, dichloropropene, trichloroethane, toluene, ethylbenzene, xylene, styrene, and trimethylbenzene were detected from the flooring of both Mugunghwa-ho and Saemaaul-ho Express passenger cabin. These compounds were also detected from the emission experiment of the seat cover. However, tetrachloroethylene and dichloroethylene were detected only from the flooring of Mugunghwa-ho Express. As a whole, VOCs emissions from the flooring of Mugunghwa-ho Express was ten times as high as those of Saemaaul-ho Express, implicating that the flooring of Mugunghwa-ho Express should be considered to be replaced by that of Saemaaul-ho Express.

The formation and emission processes of VOCs from the flooring seem to be similar to those of seat cover. However, the difference in material between the flooring (PVC) and the seat cover (polyester) might cause somehow different VOCs emissions. PVC contains many chlorine atoms, and these chlorine atoms are the possible halogen sources of halogenated VOCs. The amount of emitted halogenated VOCs from the flooring is 5~20 time higher than those from seat cover. Therefore, we could conclude that PVC materials emit much amount of halogenated VOCs compounds. Because these halogenated VOCs are mostly toxic, the use of PVC as interior materials of vehicles should be constrained.

VOCs Emission in UV Irradiation Chamber

We monitored the change of VOCs emitted from the TiO₂ coated and non-coated interior materials with first three days under dark, and following three days under UV irradiation (Figure 6). The non-coated interior material emitted large amount of VOCs initially, and the emission reached the maximum after one day. There was no more change after this point until UV light is turned on. TiO₂-coated interior material emitted less amount of VOCs initially compared to that from non-coated one, but VOCs emission reached to the similar levels to that of non-coated one after 1.5 days, followed by the decrease to the initial level. We could observe that TiO₂-coated interior materials emitted less amount of VOCs probably due to the prevention of VOCs emission by coated TiO₂ layer and the adsorption of emitted VOCs on TiO₂ surface.

When UV light was turned on, the VOC emission from both interior materials (TiO₂-coated and non-coated) drastically increased. In case of non-coated interior material, VOC emission increased up to 2,000 ppb upon the UV irradiation and the emission decreased relatively slowly. However, in case of

TiO₂-coated interior material, VOC increased up to 2,500 ppb instantly with the UV irradiation and the emission decreased relatively fast compared with that of non-coated one. This phenomenon is probably due to the photocatalytic reaction of TiO₂ to degrade VOC. The emission curve of TiO₂-coated one was not smooth, but unstable. We think this is ascribed to the production of intermediate with short lifetime during the photochemical reaction. This result showed that the VOC emission significantly increased upon the UV irradiation, and that the VOC level decreased by the photochemical reaction of TiO₂.

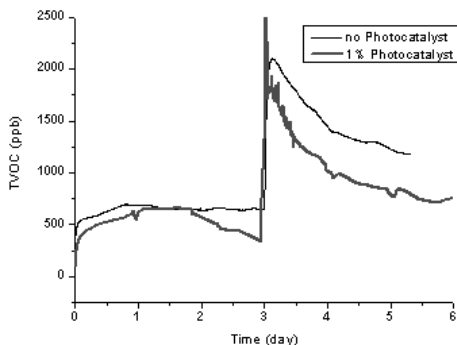


Figure 6. VOC emission change under dark and UV irradiation from TiO₂-coated interior material.

Previously, the VOC emission only under the dark condition with the conventional environmental chamber method could be investigated. However, in practical point of view, the conventional method is not adequate because VOC emission generally increased upon the sunlight irradiation condition. Especially for the interior materials of cars and railroads, they are mostly irradiated by sunlight for a long time, which may cause the increase in the VOC emission in the cabins. Hereby, we designed a new environmental chamber method with light (UV or visible) irradiation is possible. By using our method, we can evaluate the VOC emission characteristics of interior materials upon the light irradiation. We can also carry out the performance test of the photocatalyst treated interior material in degrading the hazardous organic pollutants.

Antibiotic Performance of Interior Material

We carried out the antibiotic performance test of the zeolite-coated and non-coated interior materials (Table 1 and Figure 7). As a result, we could observe that the number of microorganism drastically increased for the blank sample. And, the number of microorganism slightly increased even though the interior material was not coated with the antibiotic material. This is due to the effect of paint on the material, where the paint is somehow toxic to the microorganism. In case of zeolite-coated interior material, the number of microorganism drastically increased in our test. The number of microorganism was less than 10 cfu/mL, in case of the 0.5 wt% zeolite-coated interior materials. When the weight percentage of zeolite was increased further, no growth of microorganism was observed. So, we could find that the zeolite-coated interior material is effective to the prevention of microorganism growth.

Table 1. Antibiotic performance of zeolite-coated interior material.

Weight percentage of zeolite (%)	blank	0	0.5	1.0	2.0	5.0
Initial number of microorganism (cfu/mL)	1.9×10^5	1.9×10^5	1.9×10^5	1.9×10^5	1.9×10^5	1.9×10^5
Final number of microorganism (cfu/mL)	1.1×10^7	2.3×10^3	<10	<10	<10	<10
Antibiotic Activity (log)	---	3.6	6.0	6.0	6.0	6.0

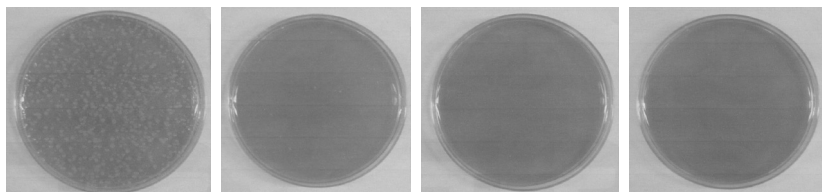


Figure 7. Antibiotic performance of blank, non-coated, 0.5 wt %, and 1.0 wt % zeolite coated ones.

CONCLUSIONS

We investigated the VOCs emissions from some interior materials of railroad passenger cabins in environmental chamber, and observed that seat cover and flooring emitted large amount of VOCs. We also measured the VOCs levels of indoor air in railroad passenger cabins under commercial services, and found that the air was contaminated by various kinds of VOCs. We concluded that the VOCs emissions from the interior materials partly contributed to the VOCs contamination of the indoor air in the railroad passenger cabin. In addition, we prepared the antibiotic interior material coated with zeolite. And, the material coated with only 0.5 weight percent of zeolite showed great performance in the prevention the grown of microorganism.

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