Experiment on Indoor Pollutants Reduction from Duct System Applied with TiO_2 Photocatalyst

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Abstract. This study analyzed the indoor pollutants (toluene, formaldehyde) reduction performance of a ventilation duct system using a titanium dioxide photocatalyst(TiO_2) to improve indoor air quality. The ventilation duct system has a loop-type closed circuit structure with a diameter of 100 mm and a length of 6.6 m that includes a reaction section to which UV lamps and photocatalysts are applied. The length of the reaction section was 0.6 m, and 0.18 m2 of the photocatalyst was applied. Toluene and formaldehyde were each injected at a concentration of 1 ppm, and the average airflow velocity inside the duct was set to 1 m/s and the experiment was performed. As a result of the experiment, toluene showed 0 ppm in 14 minutes and formaldehyde showed 0 ppm in 12 minutes after the photochemical reaction had started. Therefore, it was confirmed that the indoor pollutant concentration could be reduced when the TiO_2 photocatalyst is applied to the ventilation duct system.

Keywords. Titanium Dioxide Photocatalyst, Ventilation Duct System, Toluene, Formaldehyde, Ultraviolet, Photochemical Reaction, Reduction Test
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1. Introduction

Korea has continuously strengthened standards related to improving the energy performance of buildings to reduce national greenhouse gases, and insulation and airtightness performance have improved significantly with the goal of zero energy buildings.[1] However, the decrease in ventilation rate due to improved airtight performance, the concentration of pollutants such as carbon dioxide, formaldehyde, and volatile organic compounds generated indoors may increase.[2,3] To solve this problem, Korea is required to install a total heat exchange ventilation system in all new apartments.[4]

As a method for removing indoor pollutants, there is a method of using a photocatalyst having air purification performance in addition to ventilation.[5] Photocatalyst is a compound word of light and catalyst that promotes a chemical reaction by receiving light. Examples of the photocatalytic material include titanium dioxide (TiO_2), zinc oxide (ZnO), cadmium sulfide (CdS), tin oxide (SnO_2), vanadium oxide (V_2O_3), iron oxide (Fe_2O_3), zirconium oxide (ZrO_2), tungsten oxide (WO_3), and the like. Among them, TiO_2 is representative and is used in various places such as coating materials, concrete panels, paints, and road paving materials. TiO_2 can be used semi-permanently because its properties do not change even when it receives light, and it is widely used because it has the advantage of decomposing into water (H_2O) and carbon dioxide (CO_2) that are not harmful to the human body. [6,7]

That is, when the TiO2 photocatalyst reacts with ultraviolet rays as shown in Figure 1, electrons (e-) and electron holes are generated on the surface of the material, which again reacts with oxygen in the air to generate hydroxyl radicals (•OH) and superoxide anion radicals ($O_2\cdot^-$).[8] The generated ions react with toluene and formaldehyde (HCHO), which are indoor pollutants that cause sick building syndrome, and finally decompose into H_2O and CO_2.

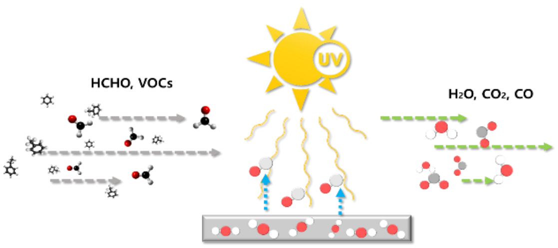

Fig. 1 - Photocatalytic reaction conceptual.

Therefore, this study is a basic research stage for the development of a mechanical ventilation system with indoor pollutant removal performance, and the photocatalytic coating material was applied to the ventilation duct system and the removal performance of toluene and formaldehyde (HCHO) was confirmed through an experiment.

2. Experiments

2.1 Experiment overview

In order to confirm the performance of removing indoor pollutants for the ventilation duct system to which the TiO_2 photocatalyst is applied, a small-scale model was produced and an experiment was performed. Currently, there is no test method for the ventilation duct system to which a photocatalyst is applied, so the conditions(UV source, light intensity, temperature, humidity, air velocity, etc.) were determined by referring to ISO 22197, an international standard photocatalyst test method. [9,10]

As shown in Table 1, the experiment was conducted with two types of representative indoor pollutants, toluene and HCHO. The light source used for the photocatalytic reaction was a UV-A lamp, and the irradiance was 10 W/m². The starting concentration of the pollutant gas is 1 ppm each. In the experiment, after stabilizing for 60 minutes after injecting the gas concentration, a UV-A lamp was turned on to perform a photoreaction, and the change in concentration was measured using the equipment shown in Table 2.

Tab. 1 - Experiment conditions.

Type of pollutants	Toluene, HCHO
Gas concentration	1 ppm each
Light source and irradiance	UV-A, 10 W/m²
Air velocity	1 m/s
Temperature	25±2.5℃
Relative humidity	RH 50%

Tab. 2 - Measuring Equipment.

Name of equipment	Airwell plus gas analyzer
Measurement material	Toluene, HCHO
Measurement range	0~10 ppm
Resolution	0.02 ppm
Measurement flow rate	1.5 L/min

2.2 Configuration of experimental device

Figure 2 shows the diagram of the small-scale photocatalytic ventilation duct system for the experiment. The total size was width 2,300.0 mm, lenght 1,060.0 mm, and height 101.8 mm. The material of the duct was made of stainless steel with low adsorption to pollutants.

Also, it consists of closed-circuit ducts and consists of photo-catalyst reaction section and non-response section. The reaction section is applied with a TiO_2 photocatalyst coating inside the duct, and the UV-A lamp is installed as shown in Figure 3. The applied coating is about 30 g, and the area of that is about 0.18 m². Figure 4 is a photo of the experimental system.

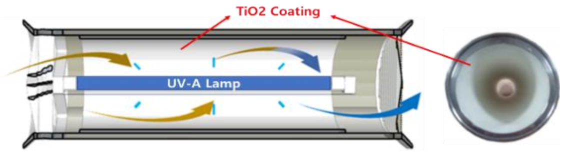

Fig. 3 - Internal composition of the photocatalyst reaction section.

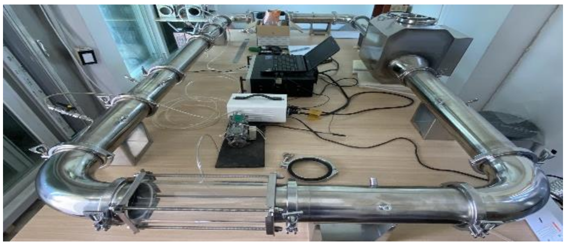
Fig. 4 - System of the duct system applied with TiO_2.

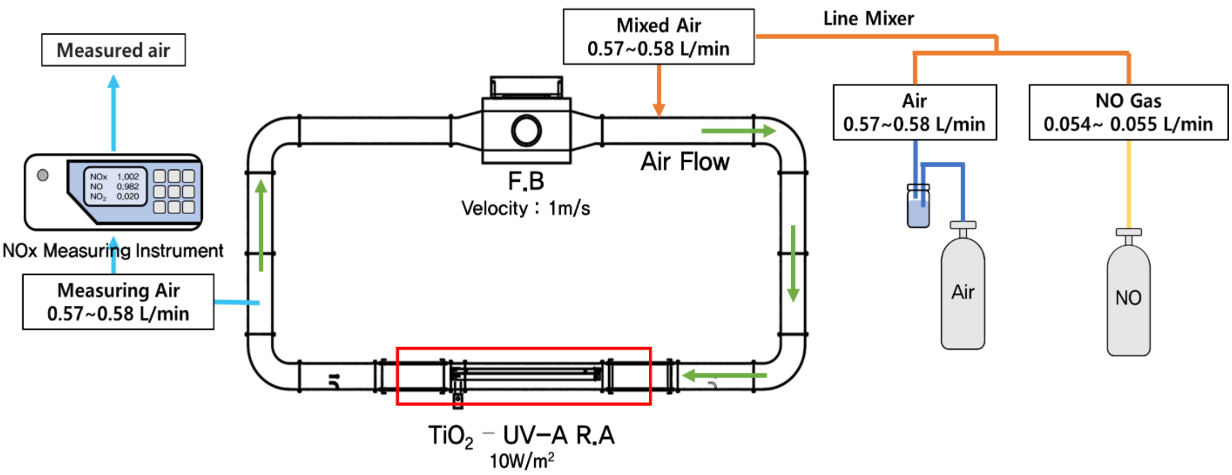

Fig. 2 - Experiment diagram of model reduction of photocatalyst ventilation duct system.

3. Results

3.1 Toluene reduction result

As a result of examining the toluene reduction performance through the experiment, Figure 5 and Table 3 are shown. After the concentration inside the ventilation duct reached 1 ppm, the UV-A lamp was turned on and the light reaction was performed, and as a result, it reached 0 ppm in 14 minutes. The removal efficiency was 100 %, and the reduction rate was 0.07 ppm/min.

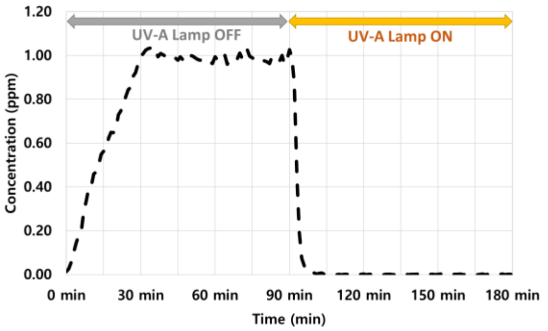

Fig. 5 - Toluene reduction graph.

Tab. 3 - Toluene reduction result.

Contents	Time	Concentration
Reaction Start	90 min	1 ppm
Reaction End	104 min	0 ppm
Reaction Time	14 min	
Reduction Rate	0.07 ppm/min	

3.2 HCHO reduction result

The results of examining the HCHO reduction performance are shown in Figure 6 and Table 4. The concentration inside the ventilation duct dropped from 1 ppm to 0 ppm in 12 minutes after the start of the photoreaction. Therefore, like toluene, the removal efficiency is 100%, and the reduction rate is 0.08 ppm/min.

4. Conclusions

This study is an experimental study to review the removal performance of indoor pollutants (Toluene, HCHO) when photocatalysts are applied to ventilation duct systems, and the results are as follows. In the case of toluene, the concentration dropped from 1 ppm to 0 ppm 14 minutes after the photocatalytic reaction decreased to 100%. In the case of HCHO, it was reduced by 100% after 12 minutes.

Therefore, through this study, it was possible to verify the indoor pollutant removal performance of the ventilation duct system using TiO_2 photocatalysts, and it is considered to be effective when combined with mechanical ventilation systems such as apartments and multi-used facilities. In the future, it is necessary to install a photocatalytic ventilation duct system for actual apartments and check the effectiveness of the actual environment through field experiments.

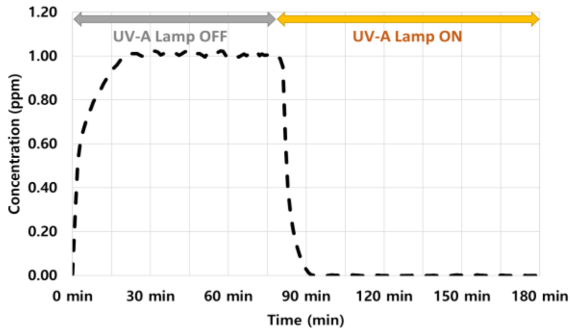

Fig. 6 - HCHO result graph.

Tab. 4 - HCHO reduction result.

Contents	Time	Concentration
Reaction Start	80 min	1 ppm
Reaction End	92 min	0 ppm
Reaction Time	12 min	
Reduction Rate	0.08 ppm/min	

5. References

[1] Kim Y., Yu K. H. Study on the Certification Policy of Zero-Energy Buildings in Korea. Sustainability. 2020;12(12):5172.

[2] Howieson S. G., Sharpe T., Farren P. Building tight – ventilating right? How are new air tightness standards affecting indoor air quality in dwellings?. Building Services Engineering Research and Technology. 2013;35(5):475-487.

[3] Park J. H., Lee S. H., Kim H. K. Effect of Mechanical Ventilation System on Improvement of Indoor Air Quality in A Newly Built Apartment and B Department Store. Journal of Korean Society of Occupational and Environmental Hygiene. 2014;24(1):38-45.

[4] Ministry of Land, Infrastructure and Transport of Korea, Rules on facility standards of buildings, MOLIT ordinance No. 23, 2013. 9. 2

[5] Song Y. W., Kim M. Y., Chung M. H., Yang Y. K., Park J. C. NOx-Reduction Performance Test for TiO2 Paint. Molecules. 2020;25(18):4087.

[6] Shayegan Z., Lee C. S., Haghighat F. TiO2 photocatalyst for removal of volatile organic

compounds in gas phase–A review. Chemical Engineering Journal. 2018;334:2408-2439.

[7] Fujishima A., Zhang X., Tryk D. A. TiO2 photocatalysis and related surface phenomena. Surface Science Reports. 2008;63(12):515-582.

[8] Ballari M. M., Hunger M., Hüsken G., Brouwers H. J. H., Modelling and experimental study of the NOx photocatalytic degradation employing concrete pavement with titanium dioxide. Catalysis Today. 2010;151(1-2):71-76.

[9] DIN German Institute for Standardization, Fine Ceramics, Test Method for Air-Purification Performance of Semiconducting Photocatalytic Materials, ISO-22197-3.

[10] DIN German Institute for Standardization, Fine Ceramics, Test Method for Air-Purification Performance of Semiconducting Photocatalytic Materials, ISO-22197-4.

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