Available online at www.sciencedirect.com
SCIENCE DIRECT
Catalysis Today 111 (2006) 271–274
CATALYSIS TODAY
www.elsevier.com/locate/cattod

Development of air purification device through application of thin-film photocatalyst

Jong-Ho Kim [a,c,*], Gon Seo [a], Dong-Lyun Cho [a], Byung-Chul Choi [b], Jong-Beom Kim [c], Hee-Ju Park [c], Myung-Wan Kim [c], Sun-Jung Song [c], Geon-Joong Kim [d], Shigekazu Kato [e]

[a] *Faculty of Applied Chemical Engineering, Chonnam National University, Gwangju 500-757, Republic of Korea*
[b] *School of Mechanical System Engineering, Chonnam National University, Gwangju 500-757, Republic of Korea*
[c] *Photo & Environmental Technology Co. Ltd., Gwangju 500-460, Republic of Korea*
[d] *Department of Chemical Engineering, Inha University, Incheon 402-751, Republic of Korea*
[e] *Photocatalytic Materials Inc. 400 Iwasaki, Komaki, Aichi, Japan*

Abstract

TiO_2 photocatalyst was prepared by hydrothermal method using titanium isopropoxide as a precursor. This photocatalyst had higher content of anatase structure and larger surface area than commercial P-25 photocatalyst. The air purification device with a filter coated with photocatalyst film was excellent in its capabilities to decompose organic materials and to kill germs. When the device was installed in hospitals, it was powerful for the sterilization of floating germs in the air. In addition, the number of germs after 7 months operation was almost the same as that obtained in the first operation.

Keywords: Photocatalysis; Thin-film photocatalyst; Air purification device; Sterilization; Floating germs

1. Introduction

Air-tightness in buildings is more emphasized than ever to save energy, which makes it difficult to drive out pollutants produced inside the buildings [1,2]. In that case, air in the buildings can cause disease such as headache, allergy, etc. to people who has stayed in the building for a long time [2]. Besides, the inside air of public facilities that is normally contaminated with bacteria, fungi, etc. threatens health of the users. Therefore, large effort has been given to develop efficient air-purifying systems [3].

Most of air-purifying systems adapt filter-type components for the cleaning of polluted air. This method may be effective for short-time use, but not for long-time use since filtering cannot remove the pollutants for good and can cause secondary pollution.

Recently, photocatalyst technology is drawing attention as a way to get rid of organic pollutants. Photocatalysts irradiated with UV rays produce OH radicals on their surface [4,5]. The strong oxidation power of OH radicals can get rid of toxic compounds, which are not easily decomposed by other methods and shows high bactericidal effect. It is well known that TiO_2 particles catalyze the killing of bacteria [6] and cancer cells [7] by UV light through the generation of free radicals by photo-excited TiO_2 particles. Therefore, they are applied in diverse fields for various purposes [8]. The most commonly used material as photocatalyst is titanium dioxide.

In this study, photocatalyst filter was prepared by coating TiO_2 films and adapted in an air-purifying device to see how well it decomposes organic materials and how effective it is for the removal of floating germs inside buildings. In addition, the chemical and physical properties of photocatalyst coated on the filter were studied.

2. Experimental

The photocatalyst material (LT) used in this study was prepared by sol–gel method. Titanium(IV) isopropoxide

* Corresponding author. Tel.: +82 62 530 1888; fax: +82 62 530 1899.
E-mail address: jonghkim@chonnam.ac.kr (J.-H. Kim).

0920-5861/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.cattod.2005.10.058

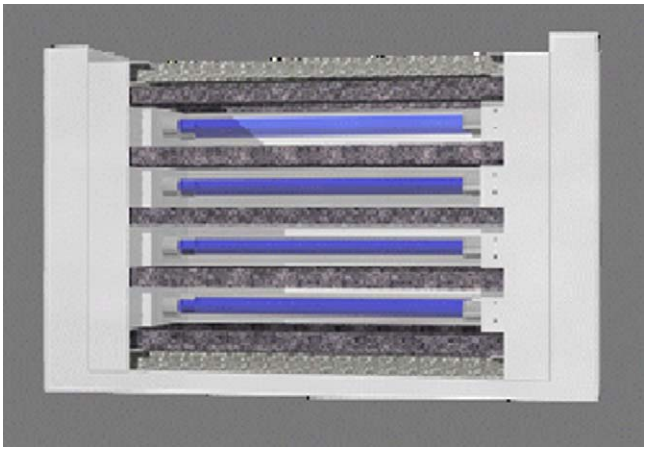

Fig. 1. Schematic diagram of an air-purifying device with the photocatalyst-coated filters.

(Aldrich Co.) (100 g) and anhydrous ethanol (20 g) was mixed. The titanium precursor was dropped little by little into distilled water (800 mL) followed by the addition of nitric acid, and the solution was stirred at room temperature. Then, the solution was heated up to 80 °C for more than 6 h to be the final product.

The crystalline structure, particle size, and surface area of the photocatalyst were analyzed by the patterns of XRD (Rigaku D/MAX-1200), TEM (JEOL, JEM-2000FXII: Korea Basic Science Institute/Gwangju Branch) photos and nitrogen adsorption experiments of powder obtained after the product was dried at 100 °C. The physico-chemical properties of the photocatalyst were compared with those of the commercial P-25 photocatalyst (Degussa).

The photocatalyst filter was prepared by coating the photocatalyst material on the SiC ceramic filter. Thickness of the coated film was estimated based on the cross-sectional view of SEM photos of photocatalyst-coated glass panel made in the same way.

Decomposition capability of acetaldehyde of the photocatalyst-coated ceramic filter was determined based on the change in the concentration, which was measured with FT-IR (BIORAD, FTS 175S). Germ-killing capability of the photocatalyst-coated filter was determined by the method previously reported [9].

Schematic diagram of an air-purifying device with the photocatalyst-coated filters is depicted in Fig. 1. It consists of a pre-filter located at the air inlet, five layers of photocatalyst-coated ceramic filters, and eight blacklight lamps.

Decomposition capability of organic materials of the air-purifying device was measured using an 800 L-capacity chamber. The air-purifying device was put into the chamber before it was sealed and organic materials were injected into it. To minimize the effect by the adsorption of the organic materials on photocatalyst filters, a fan was operated until the concentration reached the steady state value before the decomposition experiment.

For the evaluation of sterilizing capability of floating germs of the air-purifying device, an air sampler (M.A.Q.S II, OXOID Co.) was used. A BHIA was installed in the air sampler and air

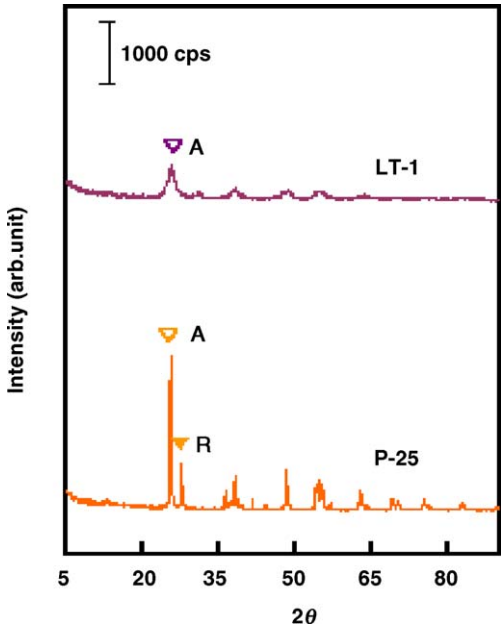

Fig. 2. XRD patterns of LT and P-25 photocatalysts.

was sucked into it for some time before and after the installation. The BHIA was cultured at about 37 °C before the number of germs was counted. The floating germs were collected at the location 10 m (3 or 15 m) away from the air-purifying device and 1.5 m above the floor.

3. Results and discussion

Fig. 2 shows X-ray diffraction patterns of powder prepared from burning and drying of photocatalyst sol (LT) and commercial P-25 powder. The peak marked "A" in Fig. 2 is a characteristic peak of anatase and the peak marked "R" is of rutile. It is known that photocatalysts with anatase structure generally have better activity than those with rutile [10]. An analysis showed that photocatalysts used in the study had more anatase than in P-25. Fig. 3 shows TEM photos of P-25 and LT. While P-25 is granular with the size of about 30 nm, LT is

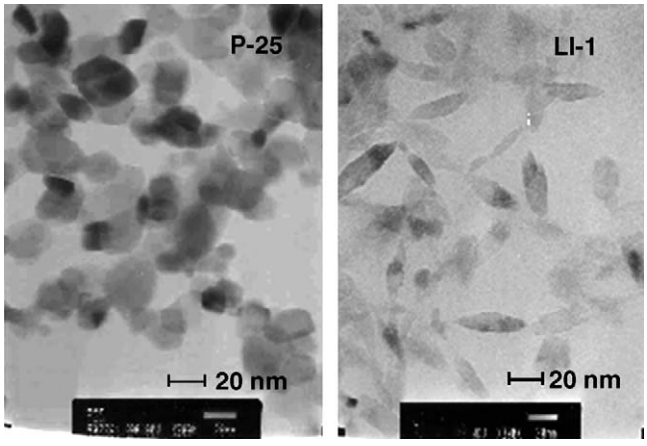

Fig. 3. TEM images of P-25 and LT photocatalysts.

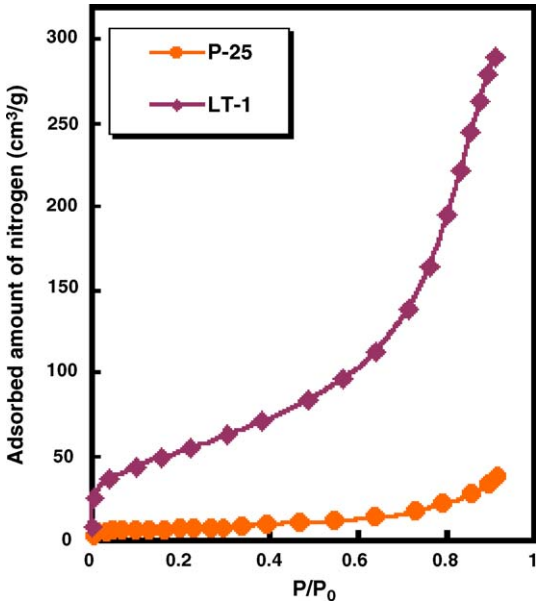

Fig. 4. N_2 adsorption isotherms of LT and P-25 photocatalysts.

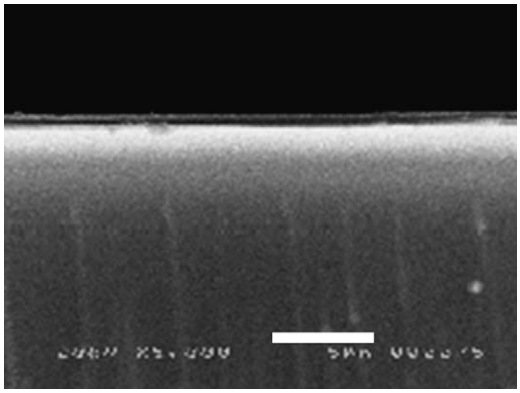

Fig. 5. SEM photo of photocatalyst-coated glass panel.

pyramid-shaped with length of about 30 nm and width of about 4–7 nm. Fig. 4 shows the nitrogen adsorption isotherm of photocatalysts. The surface area obtained from the nitrogen adsorption isotherm of P-25 was about 50 m^2/g, but LT's area was about 200 m^2/g. Fig. 5 is an SEM photo of the glass panel coated with LT. The film is smooth and even throughout the surface. It was assumed that the film coated on the filter had the same morphology as that on the glass panel.

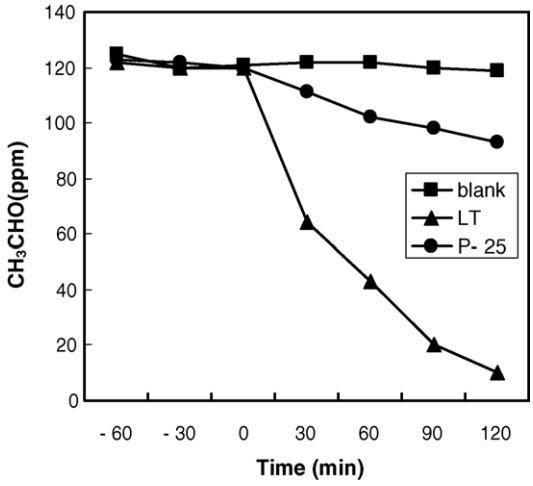

Fig. 6. Decomposition capabilities of acetaldehyde of photocatalyst-coated filters.

Fig. 6 shows decomposition capability of acetaldehyde of ceramic filter before and after the coating with photocatalysts (LT and P-25). Before the coating (blank in the Fig. 6), there is no indication of decomposition with or without irradiation of UV rays. After the coating, acetaldehyde is decomposed as much as 110 ppm in 120 min if UV rays are irradiated in LT-coated ceramic filter. The decomposition rate of LT-coated ceramic filter is much higher than that of P-25 in the same decomposition period. This result can be explained by the differences of surface area, anatase content and loading amount between LT and P-25 coated filters.

Table 1 shows germ-sterilizing capability of LT-coated filter against four kinds of germs. They killed more than 99.9% of germs used in the experiment.

Fig. 7 shows decomposing capability of typical organic materials in a large chamber. The air-purifying device showed excellent performance in the decomposition of ammonia and trimethylamine. Trimethylamine and ammonia were decomposed to about 100%, acetaldehyde, H_2S and methylmercaptan were 85%, and formaldehyde reached 75%.

Table 1
Germ-sterilizing capability of photocatalyst-coated filter

Bacteria/virus	Density	Removing rate (%)
Escherichia coli	Before measurement (X106): 156 ± 2.0; 30 min after the air sterilizer was operated (X10 2): 51 ± 1.0	99.997
Methicillin-resistant *Staphylococcus aureus*	Before measurement (X106): 123 ± 2.0; 30 min after the air sterilizer was operated (X102): 21 ± 1.5	99.998
Serratia marcescens	Before measurement (X106): 135 ± 1.0; 30 min after the air sterilizer was operated (X102): 36 ± 0.5	99.99
Influenza virus A (flu)	Before measurement (TCID50): 105.5; 30 min after the air sterilizer was operated (TCID50): 102.4	99.921

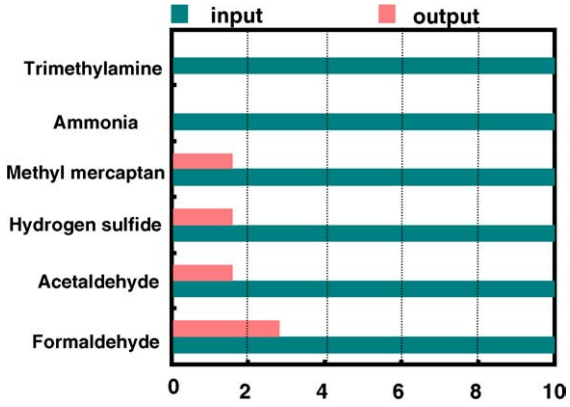

Fig. 7. Decomposing capability of typical organic materials.

Table 2
Floating germ-sterilizing capability of an air-purifying device

Date	Analysis place		
	3 m	10 m	15 m
20 July 2003	6	1	20
12 December 2003	4	2	22
12 December 2003		Lamp exchange	
25 February 2004	3	4	24

Table 2 shows the floating germ-sterilizing capability of an air-purifying device installed in J Hospital (Gwangju, Korea). It shows the numbers of floating germs at three different locations away from the air-purifying device. Before it was installed, the number of floating germs was 124 CFU/plate. After it was installed, the numbers were less than 10 CFU/plate at the locations 3 and 10 m away from the devices. The permitted standard value by the Hospital Air Quality Act of Korea is 50 CFU/plate. Even at the location 15 m away, the number was lower than the permitted standard value, 20 CFU/plate.

Table 2 also shows the floating germ-sterilizing capability of the air-purifying device after long-time operations. The numbers of germs after 5 and 7 months operations were almost the same as that obtained in the first operation. These results indicate that the ceramic filters coated with photocatalysts are excellent in their durability.

Fig. 8 shows number of floating germs at the location 10 m away from the device installed in 10 different hospitals. Before it was installed, number of floating germs was larger than the permitted standard value in most of the hospitals, which indicates that the indoor air of the hospitals is greatly polluted with germs and the air-purifying device with photocatalyst-coated filters can produce highly clean air by killing floating germs.

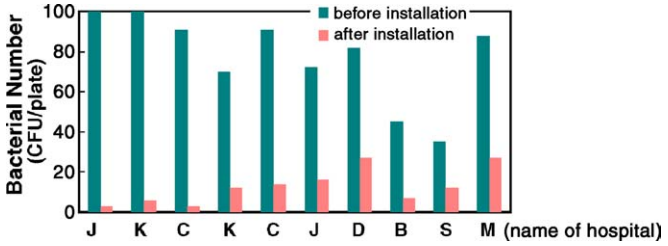

Fig. 8. Floating germ-sterilizing capability of the device installed in 10 different hospitals.

In conclusion, it has been proved that the air-purifying device with photocatalyst filters is so effective for the decomposition of hazardous organic materials and germ-sterilization.

Acknowledgements

This research was supported by the Program for the Training of Graduate Students in Regional Innovation which was conducted by the Ministry of Commerce Industry and Energy of the Korean Government. Also, this was supported by Regional Research Center for Photonic Materials and Devices at Chonnam National University under grant R12-2002-054.

References

[1] W. Jonathan, The Lancet 355 (20) (2000) 1798.
[2] ATSDR (Agency for Toxic Substances and Disease Registry), Toxicological profile for toluene, Draft. U.S. Department of Health and Human Services, Agency for Substances and Disease Registry, 1992.
[3] ACGIH (American Conference of Governmental Industrial Hygienists), Threshold Limit Value for Chemical Substances and Physical Agents and Biological Exposure Indices, ACGIH, Cincinnati, Ohio, 1994.
[4] K. Kato, A. Tsuzuki, Y. Totii, H. Taoda, T. Kato, Y. Butsugan, J. Mater. Sci. 30 (1995) 837.
[5] Y. Takahashi, K. Mita, H. Toyoki, M. Kume, J. Mater. Sci. 24 (1989) 243.
[6] (a) H.N. Pham, T. McDowell, E.J. Wikins, Environ. Sci. Health A 30 (3) (1995) 627;
(b) C. Wei, W.Y. Lin, Z. Zainal, N.E. Wililams, K. Zhu, A.P. Kruzic, R.L. Smith, K. Rajeshwar, Environ. Sci. Technol. 28 (1994) 934.
[7] R. Cai, Y. Kubota, T. Shuin, H. Sakai, K. Hashimoto, A. Fujishima, Cancer Res. 52 (1992) 2346.
[8] D.F. Ollis, C.Y. Hsiao, L. Budiman, C. Lee, J. Catal. 88 (1984) 89.
[9] S. Kato, Antibacteria Antifungi 31 (12) (2003) 783.
[10] M. Formenti, F. Juillet, P. Meriaudeau, S.J. Teichner, P. Vergnon, J. Coll. Interf. Sci. 39 (1974) 79.