

Indoor air purification by photocatalyst TiO_2 immobilized on an activated carbon filter installed in an air cleaner

C.H. Ao, S.C. Lee*

*Department of Civil and Structural Engineering, Research Center for Urban Environmental Technology and Management,
The Hong Kong Polytechnic University, Hong Kong*

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Abstract

The enhancement effect of using TiO_2 immobilized on activated carbon (TiO_2/AC) filter for removing indoor air pollutant at parts-per-billion (ppb) levels has been previously reported. To further evaluate the TiO_2/AC filter for practical application, it was installed in an air cleaner available in the commercial market and tested inside an environmental chamber. Nitrogen oxide (NO) and toluene were selected as target pollutant. Results showed that a higher removal efficiency of NO was achieved using shorter wavelength ultraviolet lamp than longer wavelength ultraviolet lamp. A higher NO removal was achieved using TiO_2/AC filter compared to TiO_2 filter only. The intermediate, NO_2 , generated from the photodegradation of NO was also successfully suppressed from exiting the system using TiO_2/AC filter. A 25% higher of nitrogen oxides (NO_x) was achieved using TiO_2/AC filter compared to the TiO_2/AC only. The higher removal efficiency of using TiO_2/AC is owing to the large adsorption capacity provided by the activated carbon. The adsorbed NO is then transferred to the TiO_2 for photodegradation. The difference in toluene removal efficiency using TiO_2/AC filter compared to the TiO_2 filter is even more significant. © 2004 Elsevier Ltd. All rights reserved.

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1. Introduction

Indoor air quality has received immense attention in the early 1990s. This is because studies (Jones, 1999; Wallace, 1991; Niemala and Vaino, 1985) showed that the level of pollutants in indoor environment is actually higher than in outdoor environment. In addition, people generally spend more than 80% of their time in indoors, which contributes a higher risk from inhalation of pollutants than outdoors (Robinson and Nelson, 1995). In 1995, USEPA identified indoor air pollution is one of the top environmental risk (USEPA, 1995).

In general, three methods are suggested to improve indoor air quality, namely source control, increase ventilation and air cleaning. Source control is often ungovernable and unavoidable in metropolis such as Hong Kong. For instance,

vehicular exhaust from nearby traffic (Li et al., 2001), building materials (Hines et al., 1993) and the use of cooking utensils (Lee et al., 2001, 2002) were inevitable sources of indoor air pollutants. Increase ventilation might even transport more pollutants from outdoor environment (Jones, 1999). Thus, air cleaning remains to be the most feasible option to improve indoor air quality.

Recently, photocatalytic oxidation has shown to be a promising and effective technology for pollution control (Yu et al., 2002; Fujishima et al., 2000; Obuchi et al., 1999; Peral et al., 1997; Hoffmann et al., 1995). Unlike traditional pollution control method such as adsorption which merely transfers pollutant from gaseous phase to solid phase, PCO actually oxidizes pollutants to CO_2 and H_2O . However, studies (Luo and Ollis, 1996; Kim and Hong, 2002) showed that the rate of PCO decreased with decreasing pollutant concentration. In addition, at high humidity levels, water vapor competed with TiO_2 for adsorption sites which further decreased the rate of PCO (Ao et al., 2003a,b). Thus,

* Corresponding author. Tel.: +852-2766-6011; fax: +852-2334-6389.
E-mail address: ceslee@polyu.edu.hk (S.C. Lee).

in indoor environment where the pollutant concentration is only parts-per-billion (ppb) levels and under high humidity levels, the rate of PCO is rather low.

To improve this situation, Shiraishi et al. (2003) used an adsorbent to adsorb the pollutants to increase the pollutant concentration from the diluted air stream. The pollutant concentrated on the adsorbent was then desorbed upon heating, followed by TiO_2 photocatalytic oxidation. The HCHO removal efficiency was three times higher using the combination of adsorption/desorption and PCO compared to PCO only. Our group has also developed an activated carbon filter immobilized with TiO_2 (TiO_2/AC) to overcome the competition effect between the water vapor and the pollutant at ppb level for indoor air purification (Ao and Lee, 2003). The removal efficiency of TiO_2/AC was seven times higher than TiO_2 only under high humidity levels for multiple indoor air pollutants removal (Ao and Lee, 2004).

The aim of this study is to further investigate the feasibility of TiO_2/AC for practical indoor air purification. The TiO_2/AC filter was installed in an air cleaner available in the commercial market. The air cleaner was then evaluated inside an environmental chamber. Nitrogen oxide (NO) and toluene were selected as target pollutant as these pollutants are commonly found in indoor air. Sensitive analyses were conducted using different UV lamps and filter combinations. To the best of our knowledge, no detailed investigation has been reported on the evaluation of TiO_2 immobilized on an activated carbon filter installed in an air cleaner.

2. Experimental

2.1. Reagents and catalyst preparation

NO (BOC gas) was used as reactant gas and acquired from compressed gas cylinder at a concentration of $50 \text{ ppm} \pm 2\%$ with nitrogen as balanced gas with traceable National Institute of Standards and Technology (NIST) standard. Toluene (Riedel-de Haen, reagent grade, 99.7%) was acquired from liquid phase.

TiO_2 (Degussa P-25) was used as a photocatalyst without any pretreatment. Activated carbon filter was purchased from a local company. The Brunauer–Emmett–Teller (BET) surface was $1115 \text{ m}^2/\text{g}$. Using the desorption branch of the isotherm and the Barrett–Joyner–Helenda (BJH) formula, the average pore size was estimated to be 3.4 nm. The preparation of the TiO_2 filter and TiO_2/AC filter was described in elsewhere (Ao and Lee, 2003). Water suspension with 5% of TiO_2 was coated on a glass fiber filter (Whatman) as a supporting substrate (TiO_2 filter). It was then calcinated at 120°C for 1 h with a temperature gradient of $5.5^\circ\text{C}/\text{min}$. The same procedure was followed for TiO_2 loaded on activated carbon filter (TiO_2/AC), except an activated carbon filter ($23.085 \text{ g} \pm 0.5\%$) was used instead of a glass fiber filter. The surface area of the glass fiber filter was identical to the activated carbon, which was 300 cm^2 used in this study.

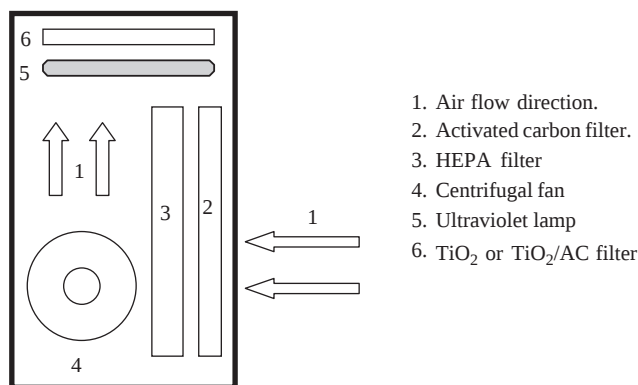


Fig. 1. Schematic diagram of the air cleaner.

The amount of TiO_2 imposed was determined by the weight difference before and after the coating procedure. In all experiments, the weight of TiO_2 imposed is $1.17 \text{ g} \pm 5\%$.

2.2. Environmental chamber

An electropolished stainless steel environmental chamber with a volume of 2.38 m^3 was used in this study (Lee et al., 2003; Kwok et al., 2003; Lam et al., 2001). The temperature and relative humidity in all studies were $24 \pm 1^\circ\text{C}$ and $70\% \pm 5\%$, respectively. Four mixing fans were installed at the bottom corners of the chamber to ensure adequate mixing of air. The temperature and relative humidity were continuously monitored by portable Q-Trak monitor (Model 8550, TSI, MN, USA). After each test, the chamber was cleaned by scrubbing the inner surfaces with deionized and distilled water. The chamber was then conditioned by purging zero air (Thermo Environmental Inc. Model 111) and conditioned to 25°C and 70% relative humidity for at least 24 h prior to testing. The chamber background level was measured before each experiment.

2.3. Air cleaner

As shown in Fig. 1, the air cleaner is equipped with a high-efficiency particulate air filter (HEPA) and an activated carbon filter (AC). Illumination was provided by a 6 W ultra violet germicidal lamp (Sankyo Denki, Japan). The wavelength of the germicidal lamp ranged from 200 to 300 nm with the maximum light intensity at 254 nm (denoted as UVC). The ultra violet germicidal lamp can be interchanged by a 6 W black lamp (Sankyo Denki, Japan), depending on the experimental settings. The wavelength of the black lamp ranged from 300 to 400 nm with a maximum light intensity at 365 nm (denoted as UVA). A centrifugal fan is used to draw air at the front of the air cleaner and exhausted on the top, as indicated by the airflow directions in Fig. 1. The flowrate used in all study was $5.1 \text{ m}^3/\text{min}$. The TiO_2 filter or the TiO_2/AC filter was mounted 1 cm on top of the UV lamp. The UV intensity measured (UVP radiometer, model

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