Photodecomposition of gaseous toluene using TiO$_2$ prepared by SANSS

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Abstract: This study examined the photodecomposition of volatile organic compounds (VOCs) using TiO$_2$ catalyst fabricated by the Submerged Arc Nanoparticle Synthesis System (SANSS). The TiO$_2$ catalyst was employed to decompose gaseous toluene and compared with Degussa-P25 TiO$_2$ in terms of decomposition efficiency. It was found that gaseous toluene exposed to UV irradiation produced intermediates that were even harder to decompose. After 60-min of photocomposition, Degussa-P25 TiO$_2$ reduced the concentration of gaseous toluene to 8.18% while the concentration after decomposition by SANSS TiO$_2$ catalyst dropped to 0.35%. The results show that TiO$_2$ prepared by SANSS has great efficiency in decomposing both gaseous toluene and its intermediates.

1. Introduction

Indoor air quality within buildings is a critical concern, since urban dwellers generally spend more than 80% of their time in an indoor environment. Indoor air pollutants mainly include nitrogen oxides (NO$_x$) and volatile organic compounds (VOCs), which can cause adverse health effects [1]. VOCs are primarily composed of BTEX (benzene, toluene, ethylbenzene, and o-xylene) and halogenated hydrocarbons [2]. Moctezuma et al. [3] reported that under irradiation at 254 nm, TiO$_2$ catalysts can decompose organic compounds. Juyoung et al. [4] found that UV irradiation at 254+185 nm shows better capacity in decomposing gaseous toluene than UV irradiation at 365+254 nm. Chang et al. [5] employed SANSS TiO$_2$ catalyst to absorb and decompose methylene blue. They found that a TiO$_2$
catalyst prepared by SANSS showed a high surface absorption and decomposition capacity for methylene blue. In this study, we examined the photocomposition of gaseous toluene by SANSS TiO$_2$ catalyst and compared its efficiency with that of Degussa-P25 TiO$_2$.

2. SANSS TiO$_2$ and Degussa-P25 TiO$_2$ preparations

The sample of TiO$_2$ catalyst used in this study was prepared by the submerged arc nanoparticle synthesis system (SANSS). In the electric discharge manufacturing process, a Ti bar, applied as the electrode, was melted and vaporised under high temperature. The vaporised Ti powders were then rapidly quenched under low-temperature and low-pressure conditions in deionized water, thus nucleating and forming nanocrystalline powders uniformly dispersed in the base solvent [6]. Figure 1 shows the TEM image of the SANSS TiO$_2$ nanofluid thus obtained. The diameter of the SANSS TiO$_2$ nanoparticles measured by the dynamic light scattering particle size distribution analyzer (HORIBA, LB-500) was 10 nm. X-ray diffraction analysis confirmed that the nanoparticles in the deionized water were Anatase TiO$_2$.

Degussa-P25 TiO$_2$ (75% anatase/25% rutile) with a BET surface area of 50m$^2$ g$^{-1}$ was purchased from Nippon Aerosil Co. Ltd.

3. Experimental design

The TiO$_2$ nanofluid fabricated using SANSS was left to stand for 7 days. The experiment used only the fluid closer to the surface that showed better particle suspension. The absorption spectra of the SANSS TiO$_2$ nanofluid were measured using a range of UV-visible spectrophotometers. Degussa-P25 TiO$_2$ was then added to the deionized water to yield nanofluids of various concentrations. For example, the concentration of the SANSS TiO$_2$ nanofluid shown in Figure 2 was 16mg/L. Then 0.2 ml of the sample nanofluid was dropped onto a glass slide and dried in an oven at 50°C.

Figure 3 shows the experimental setup. The experiments were conducted under a constant temperature of 30°C. First, 0.001 ml of fluid toluene was injected into the quartz cuvette (Hellma 117-QS) and then vaporised to become gaseous toluene. The UV lamp (Sankyo Denki Co. Ltd., Japan) used was a G10T8 low-pressure mercury lamp with a maximum emission at 253.7 nm and a smaller (<5%) emission at 184.9 nm. The electric power consumption of all UV lamps were identical (10 W). The photodecomposition experiments were conducted under different settings. They were Group I: no UV irradiation or TiO$_2$ decomposition; Group II: no UV irradiation but with Degussa-P25 TiO$_2$; Group III: with TiO$_2$ prepared by SANSS decomposition but no UV irradiation; Group IV: with UV irradiation but without TiO$_2$ decomposition; Group V: with UV irradiation and Degussa-P25 TiO$_2$ decomposition; and Group VI: with both UV irradiation and TiO$_2$ prepared by SANSS decomposition. The changes in concentration of gaseous toluene were measured every 5 minutes for 1 hour by a range of UV-visible spectrophotometers and analyzed by computer.

4. Results & Discussion

Figure 4 shows the changes in concentration of gaseous toluene with time. As can be seen, there is little absorbance or change in the concentration of gaseous toluene after the 60 minutes test under no UV irradiation and without TiO$_2$ decomposition (Group I). For Group IV, under UV irradiation, gaseous toluene produced intermediates [7] whose absorbance is higher than that of original gaseous toluene. As seen in Figure 4, the concentration of gaseous toluene rose to 129.72% within the first 15 minutes; thereafter, the decrease in gaseous toluene concentration also led to a reduction in intermediates produced. Because the intermediates were even harder to decompose than gaseous toluene, part of them were found attached to the surface of the quartz cuvette. At 60 minutes, the concentration of gaseous toluene dropped to 60.26%. Similar to Group I, in the absence of UV irradiation, there is barely any change in the concentration of gaseous toluene by TiO$_2$ prepared by SANSS decomposition in Group III. Group VI shows the most significant changes. Under UV irradiation, TiO$_2$ prepared by SANSS decomposition brought the concentration of gaseous toluene down to 92.04% within the first 15 minutes and the concentration was reduced to only 0.35% after 60
minutes. This proves that TiO₂ prepared by SANSS has good decomposition efficiency for both gaseous toluene and its intermediates under 253.7±184.9 nm UV irradiation. Group V, like Group IV, saw an increase in VOC concentration to 107.4% due to UV irradiation. The lower concentration than that of Group II revealed that Degussa-P25 TiO₂ was also capable of decomposing the intermediates produced by gaseous toluene. After 60 minutes, the concentration of gaseous toluene was reduced to 8.18%. Comparison between the percentage of reduction in concentration of gaseous toluene shows that TiO₂ prepared by SANSS has greater efficiency than Degussa-P25 TiO₂ in decomposing gaseous toluene and its intermediates.

5. Conclusion
From the above results and analysis, we conclude the following.

1. Under UV irradiation, gaseous toluene produced intermediates that are even harder to decompose than gaseous toluene and tends to attach to the surface of materials.
2. Under UV irradiation at 253.7±184.9 nm, TiO₂ prepared by SANSS can produce strong chemical debonding energy, thus showing great efficiency, superior to that of Degussa-P25 TiO₂, in decomposing gaseous toluene and its intermediates.

Figure 1. TEM image of TiO₂ prepared by SANSS
Figure 2. Absorption spectrum of TiO₂
Figure 3. Experimental setup
Figure 4. Changes in concentration of gaseous toluene with time
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