available at www.sciencedirect.com

journal homepage: www.elsevier.com/locate/chnjc

Article

Iron-impregnated titania composites for the decomposition of low-concentration aromatic organic pollutants under UV and visible light irradiation

Wan-Kuen Jo*, Joon Yeob Lee

Department of Environmental Engineering, Kyungpook National University, Daegu, 702-701, Korea

ARTICLE INFO

Article history:

Received 7 June 2013

Accepted 20 August 2013

Published 20 December 2013

Keywords:

Nanoparticle

Photocatalyst characteristic

Impregnation ratio

Indoor air purification

ABSTRACT

Fe-TiO₂ photocatalysts with different ratios of Fe to Ti were prepared by a sol-gel process using tetra-*n*-butyl titanium and iron(III) nitrate as Ti and Fe sources, respectively. The photocatalytic function of the prepared composites was examined for the decomposition of low-concentration (0.1 ppm) airborne benzene, toluene, ethyl benzene, and *o*-xylene (BTEX). The Fe-TiO₂ composites were characterized by energy dispersive X-ray spectroscopy, X-ray diffraction, UV-visible spectroscopy, and Fourier transform infrared spectroscopy. The time-series ratios of outlet to inlet concentrations of toluene, ethyl benzene, and *o*-xylene target chemicals, as determined by the Fe-TiO₂ composites under visible light exposure, were lower than or similar to those of the reference TiO₂ photocatalyst. Moreover, the time-series ratios of outlet to inlet concentrations of the three compounds, as determined for the Fe-TiO₂ composites, increased as the ratio of Fe to Ti increased from 0.001 to 0.010. In contrast, under UV exposure, the time-series ratios of outlet to inlet concentrations of BTEX, determined for the Fe-TiO₂ composites, were similar to or higher than those obtained from the reference TiO₂ photocatalyst. Fe-TiO₂ composites with an optimal Fe to Ti ratio could effectively be applied for the purification of low-concentration aromatic organic pollutants.

© 2013, Dalian Institute of Chemical Physics, Chinese Academy of Sciences.

Published by Elsevier B.V. All rights reserved.

1. Introduction

Aromatic organic pollutants have received a great deal of attention owing to their frequent detection in high concentrations in urban outdoor and indoor environments, and their health hazards. These pollutants primarily originate from anthropogenic sources, including traffic emissions, industrial combustion emissions, and petroleum and solvent handling processes [1]. The atmospheric pollutants can penetrate into buildings, thereby elevating indoor concentrations [2]. Moreover, there is a variety of indoor pollutant sources such as household products, furniture, and building finishing materials [3]. Several research groups showed that both outdoor and indoor pollutant sources could elevate indoor concentrations

above ambient air concentrations in urban areas [3]. High indoor pollutant concentrations have frequently been associated with sick building syndrome symptoms such as eye irritation, dizziness, headache, and nausea [4]. The health hazards associated with these aromatic organic pollutants have thus prompted the application of controlled measures to decrease indoor concentrations.

TiO₂-based photocatalysis is a promising technique for the purification of a variety of environmental pollutants [5–7]. Unlike conventional adsorption techniques that simply transfer gaseous pollutants to a solid phase [8], photocatalytic processes have the potential to convert a variety of organic pollutants to innocuous species such as carbon dioxide and water vapor via oxidation reactions as promoted by hydroxyl radicals and

* Corresponding author. Tel: +82-53-9506584; Fax: +82-53-9506579; E-mail: wkjo@knu.ac.kr

DOI: 10.1016/S1872-2067(12)60688-3 | http://www.sciencedirect.com/science/journal/18722067 | Chin. J. Catal., Vol. 34, No. 12, December 2013

super-oxide ions, generated during the photocatalytic processes [9,10]. However, the environmental application of TiO_2 particles has often been limited by low quantum yields because of the high recombination rates of the photon-induced electron-hole pairs and the wide band gap of TiO_2 (3.0 and 3.2 eV for rutile and anatase phases, respectively) [11]. Previous researchers [12–15] have endeavored to overcome this drawback by impregnating the TiO_2 particles with transition metals. A range of transition metal-impregnated TiO_2 particles that featured reduced electron-hole pair recombination processes and lower band gap energy relative to pure TiO_2 , thereby improving the photocatalytic performance of TiO_2 , have been reported.

Iron is an effective transition metal that can be impregnated into TiO_2 nanoparticles to enhance the photocatalytic performance of TiO_2 towards the decomposition of environmental pollutants in the aqueous phase [15–18]. Iron is also much cheaper than noble metals such as Pd, Pt, Rh, Ag, and Au. However, the application of Fe-impregnated TiO_2 (Fe- TiO_2) composites for the purification of indoor air pollutants, present at the sub-ppm level, has yet to be fully addressed. Air application studies are usually conducted at high ppm concentration conditions (15 to hundreds of ppm) [17,18]. However, extrapolation of the photocatalytic decomposition performance results, obtained at concentrations greater than those in the intended application, is likely to be inappropriate [19]. The mass ratio of Fe to Ti may also be an important factor to consider for the application of Fe- TiO_2 composites for sub-ppm level indoor air purification. Accordingly, in this study, Fe- TiO_2 composites with different Fe/Ti ratios were prepared to examine their suitability as photocatalysts for the photocatalytic decomposition of low-concentration (0.1 ppm) airborne aromatic organic pollutants (such as benzene, toluene, ethyl benzene, and *o*-xylene (BTEX)).

2. Experimental

2.1. Preparation and characterization of Fe- TiO_2 composites

Fe- TiO_2 composites with different mass ratios of Fe to Ti were fabricated by a sol-gel process using tetra-*n*-butyl titanium ($\text{Ti}(\text{OC}_4\text{H}_9)_4$, Sigma-Aldrich) and iron(III) nitrate ($\text{Fe}(\text{NO}_3)_3$, Sigma-Aldrich) as Ti and Fe sources, respectively. $\text{Ti}(\text{OC}_4\text{H}_9)_4$ solution (25 mL) was added dropwise to a mixture of 100 mL ethanol (Sigma-Aldrich), 8 mL deionized water, 10 mL acetic acid (Sigma-Aldrich), and a designated amount (0.025, 0.100, 0.175, or 0.250 g) of $\text{Fe}(\text{NO}_3)_3$. This corresponds to Fe- TiO_2 composites with the respective Fe/Ti mass ratios of 0.001, 0.004, 0.007, and 0.010, which were defined as FT-0.001, FT-0.004, FT-0.007, and FT-0.010, respectively. The resulting mixture was stirred for 2 h and then aged for 48 h to obtain a gel substrate. The final product was dried at 80 °C for 48 h and then calcined at 500 °C for 3 h to give a Fe- TiO_2 composite. TiO_2 reference photocatalyst, denoted as FT-0, was also prepared using the same process in the absence of the Fe species.

The Fe- TiO_2 composites were characterized using energy dispersive X-ray spectroscopy (EDX), X-ray photoelectron

spectroscopy (XPS), transmission electron microscopy (TEM), X-ray diffraction (XRD), UV-visible spectroscopy, and Fourier transform infrared (FTIR) spectroscopy. Elemental analysis of the samples was performed on a scanning electron microscope fitted with an EDX unit (EDX-350 FE-SEM). XPS was carried out on a PHI Quantera SXM using Al K_α radiation. Morphological properties were determined on a transmission electron microscope (Hitachi H-7600) operating at 100 kV. The crystal structure of the photocatalysts was determined using a Rigaku D/max-2500 diffractometer with Cu K_α radiation in the range of $2\theta = 20^\circ$ – 80° . UV-visible light absorption properties of the prepared materials were examined on a Varian CARY 5G diffuse reflectance ultraviolet-visible-near infrared spectrophotometer. The structural characteristics were determined using an FTIR spectrophotometer (Spectrum GX, Perkin Elmer Inc.) at a resolution of 4 cm^{-1} in the spectral range of 400–4000 cm^{-1} . The Brunauer-Emmett-Teller (BET) surface areas of the photocatalysts were determined using the N_2 adsorption-desorption method.

2.2. Photocatalytic activity tests

The photocatalytic activity of the Fe- TiO_2 composites with different Fe/Ti ratios (FT-0.001, FT-0.004, FT-0.007, and FT-0.010) for the photocatalytic decomposition of aromatic organic pollutants was determined by a continuous-flow reactor. For comparison, the photocatalytic activity of the prepared TiO_2 and P25 TiO_2 was also investigated for the same target compounds under the same operational conditions. The photocatalytic reactor comprised a Pyrex tube with a length of 26.5 cm and an inner diameter of 3.8 cm, and a cylindrical-shaped 8 W fluorescent daylight lamp (F8T5DL, Youngwha Lamp Co.) with a spiral range of 400–720 nm or an 8 W fluorescent black-light lamp (F8T5BL, Youngwha Lamp Co.) with a peak spectral intensity of 352 nm. The Fe- TiO_2 composite or P25 TiO_2 powder was coated onto the inner surface of the Pyrex tube according to a method reported by Xagas et al. [20]. Other major portions of the experimental set up include a clean dried air cylinder, humidification apparatus, and standard gas preparation device. Clean dried air supplied by the air cylinder was subjected to a secondary purification process by allowing the air to flow through a hydrocarbon filter. The resulting stream of dried air was allowed to flow into the humidification apparatus, which consisted of water-containing glass bulbs that were partially immersed in a water bath. The standard gas was synthesized by mixing the humidified air with the liquid standard compounds that were injected into a mixing chamber via a syringe pump (KD Scientific 210), after which it was transferred to the annular region of the photocatalytic reactor.

The photocatalytic operational parameters were as follows: air flow rate = 1 L/min, initial concentration of target compounds 0.1 ppm, and relative humidity = 45%. The light intensity supplied by the visible and UV lamps was 2.9 and 0.3 mW/cm^2 , respectively, at an equivalent distance of half the hydraulic diameter of the photocatalytic reactor as measured from the light source. The tests were performed in triplicates to obtain reliable results.

Fig. 1. Energy dispersive X-ray spectra of P25 TiO₂ (a), prepared TiO₂ (FT-0) (b), and Fe-TiO₂ composites with varying Fe/Ti ratios (FT-0.001 (c), FT-0.004 (d), FT-0.007 (e), and FT-0.010 (f)).

The measurements of gaseous species in the air stream were conducted at upstream and downstream ports of the Pyrex reactor to assess the photocatalytic decomposition efficiencies of the target compounds. Air sampling was conducted using an empty Teflon bag, after which air was drawn through a stainless steel trap containing Tenax TA adsorbent. Sampling time varied from 3 to 5 min depending on the desired sampling amount. The collected gaseous compounds were analyzed on a gas chromatograph-mass spectrometer (Perkin Elmer Clarus SQ 8) coupled with an automatic-programmed thermal desorption apparatus (Perkin Elmer ATD 350). The target chemicals were qualitatively analyzed using both their retention time and mass spectra (using the Wiley 275 software library). Quantitative analysis of the gaseous compounds was conducted using calibration equations as determined using five concentrations normalized to an internal standard compound. The quality assurance process for the air measurements included analysis of laboratory blank and spiked standard samples. The detection limit for this method ranged from 0.04 to 0.13 ppb depending on the target chemical.

3. Results and discussion

3.1. Characteristics of Fe-TiO₂ composites with varying Fe/Ti ratios

Fe-TiO₂ composites with varying Fe/Ti ratios, prepared TiO₂, and P25 TiO₂ reference photocatalyst were characterized by EDX, XRD, UV-Vis spectroscopy, and FTIR. As shown in Fig.

1, EDX spectra of all the Fe-TiO₂ composites exhibited peaks corresponding to Ti, O, and Fe whereas neither the prepared TiO₂ nor P25 TiO₂ featured Fe peaks. Likewise, Azad et al. [21] demonstrated the presence of Fe atoms in electrospun Fe-TiO₂ nanofibers prepared using 5% Fe₃O₄ using EDX. The observed Pt peaks were due to the Pt coating pretreatment of the samples. The Fe/Ti ratios, as obtained from the EDX results, matched with the calculated values used for the preparation of the Fe-TiO₂ composites (Table 1). XPS analysis further confirmed the presence of Ti and O atoms in the Fe-TiO₂ composites (Fig. 2). However, Fe signals were non-detectable. This was due to the small amounts of Fe embedded into TiO₂ that

Fig. 2. X-ray photoelectron spectra of Fe-TiO₂ composites with varying Fe/Ti ratios.

Table 1

Physical properties of P25 TiO₂, prepared TiO₂, and Fe-TiO₂ composites.

Sample	Content of anatase phase	Diameter of anatase (nm)	Diameter of rutile (nm)	Ratio of Fe to Ti	BET surface area (m ² /g)
P25 TiO ₂	0.8	21.3	26.8	NA	55.4
Prepared TiO ₂	1.0	20.7	NA	0.000	55.8
FT-0.001	1.0	20.5	NA	0.001	64.1
FT-0.004	1.0	18.7	NA	0.004	63.2
FT-0.007	1.0	20.0	NA	0.008	61.6
FT-0.010	1.0	19.8	NA	0.010	58.4

NA: measurements were not applicable.

Fig. 3. Transmission electron microscopy images of P25 TiO₂ photocatalyst (a), prepared TiO₂ (FT-0) (b), and Fe-TiO₂ composites with varying Fe/Ti ratios (FT-0.001 (c), FT-0.004 (d), FT-0.007 (e), and FT-0.010 (f)).

were below the instrumental detection limit. XPS peaks at 710.9 and 724.8 eV, which correspond to the binding energy of Fe 2p_{3/2} and Fe 2p_{1/2} of Fe³⁺, respectively, have been reported by Ghorai et al. [22].

TEM images of the reference TiO₂ photocatalyst and Fe-TiO₂ composites are shown in Fig. 3. The nanoparticles of the prepared photocatalysts were homogeneously distributed within the photocatalyst matrix. As shown in Fig. 4, both the Fe-TiO₂ composites and prepared TiO₂ photocatalyst displayed anatase peaks only with a main peak at $2\theta = 25.3^\circ$, whereas P25 TiO₂ photocatalyst featured both anatase and rutile peaks. Likewise, previous researchers [16,17] have reported the presence of the anatase phase only (using XRD) in various Fe-TiO₂ composite materials prepared via diverse synthetic routes. It should also be noted that no Fe-associated peaks were observed at the Fe/Ti ratios studied (Fig. 4). This was consistent with the reported studies by Liu et al. [23]: Fe-TiO₂ composites prepared with a Fe/Ti ratio of 0.01 did not feature any Fe-related diffraction peaks unlike Fe-TiO₂ composites prepared with a Fe/Ti

ratio of 0.03, which exhibited a Fe-associated diffraction peak at $2\theta = 36.9^\circ$. Accordingly, the low amounts of Fe ions, impregnated in TiO₂, could not be detected by the instrument most likely because of its limited detection sensitivity.

The content of the anatase phase and the crystal size of the reference TiO₂ photocatalyst and Fe-TiO₂ composites were calculated using the Spurr equation [24] and Scherrer formula [25], respectively. As shown in Table 1, P25 TiO₂ comprised 80% anatase with a corresponding anatase diameter of 21.3 nm, whereas the anatase diameter of the prepared TiO₂ was 20.7 nm. The anatase diameters of the Fe-TiO₂ composites ranged from 18.7 to 20.5 nm, which were comparable to the size of the reference TiO₂ photocatalysts. These findings suggested that Fe³⁺ ions did not significantly influence the crystal size of the prepared photocatalysts. In contrast, Cui et al. [16] reported anatase diameters of 12.0, 13.4, 12.6, 16.4, and 12.3 nm for the corresponding prepared non-modified TiO₂ and Fe-TiO₂ composites with Fe/Ti ratios of 0.001, 0.005, 0.010, and 0.015. The variation in the anatase diameters between the latter and our studies was attributed to the different synthesis routes employed. Cui et al. [16] adopted a thermal hydrolysis method followed by a calcination treatment.

Figure 5 shows the UV-Vis absorbance spectra of the reference TiO₂ photocatalyst and the Fe-TiO₂ composites. P25 TiO₂ displayed an absorption edge at $\lambda \approx 410$ nm, which was consistent with that reported by other researchers [18,26]. Similarly, the prepared TiO₂ exhibited an absorption edge near to the UV range. In contrast, the absorption spectra of the Fe-TiO₂ composites were substantially shifted towards the visible light region, which was in good agreement with the results reported by Sun et al. [18]. Moreover, the Fe-TiO₂ composites showed increasing red shifts with increasing amounts of Fe. The red shifts were ascribed to the high charge transfer between Fe and TiO₂ because of the presence of impregnated Fe atoms that would provide impurity levels within the band gap of TiO₂ [27,28]. These results suggest that the Fe-TiO₂ composites

Fig. 4. X-ray diffraction patterns of P25 TiO₂ photocatalyst, prepared TiO₂ (FT-0), and Fe-TiO₂ composites with varying Fe/Ti ratios.

Fig. 5. UV-Vis spectra of P25 TiO₂ photocatalyst, prepared TiO₂ (FT-0), and Fe-TiO₂ composites with varying Fe/Ti ratios.

Fig. 6. Fourier transform infrared spectra of P25 TiO₂ photocatalyst, prepared TiO₂ (FT-0), and Fe-TiO₂ composites with varying Fe/Ti ratios.

would be effectively activated under both visible light and UV irradiation.

FTIR spectra of the reference TiO₂ photocatalysts and Fe-TiO₂ composites are shown in Fig. 6. Both the reference TiO₂ photocatalysts and Fe-TiO₂ composites exhibited two main bands at 3435 and 1631 cm⁻¹ that correspond to the O-H stretching vibration and O-H bending of water molecules adsorbed onto the surface of the nanoparticles, respectively [29]. This was consistent with the reported study by Mozia et al. [30] who observed two absorption bands in the regions of 3300–3500 cm⁻¹ and 1630–1640 cm⁻¹, respectively, for Fe-TiO₂ nanoparticles prepared using TiO₂ powder and Fe(CH₃COO)₂. The

broad band at 682 cm⁻¹ observed for the reference TiO₂ photocatalyst was associated with TiO₂ crystal lattice vibrations [29]. This band was shifted to a lower frequency of 535 cm⁻¹ in both the prepared TiO₂ and Fe-TiO₂ composites. The shift was likely caused by the interaction with Fe elements impregnated into TiO₂ [30].

3.2. Photocatalytic activity

The photocatalytic decomposition efficiency of BTEX (benzene, toluene, ethyl benzene, and *o*-xylene) by the reference

Fig. 7. Time-series ratios of outlet (C_0) to inlet (C_i) concentrations of benzene (a), toluene (b), ethyl benzene (c), and *o*-xylene obtained (d) over P25 TiO₂ photocatalyst, prepared TiO₂ (FT-0), and Fe-TiO₂ composites with varying Fe/Ti ratios under visible light irradiation. The legend in (a) applies to all graphs.

TiO₂ photocatalysts and Fe-TiO₂ composites was evaluated under visible light and UV irradiation following adsorption in the dark. A control test that was performed using a Pyrex reactor in the absence of a photocatalyst coating showed that the photolysis of TEX was insignificant under both visible light and UV irradiation. Figure 7 shows the time-series ratios of outlet to inlet concentrations of BTEX determined by the reference TiO₂ photocatalysts and Fe-TiO₂ composites over a 3-h photocatalytic run under visible light irradiation. The time-series ratios of outlet to inlet concentrations for the following three target chemicals, toluene, ethyl benzene, and *o*-xylene, determined by the Fe-TiO₂ composites were lower than or similar to those determined by the reference TiO₂ photocatalysts. More specifically, the average ratios of outlet to inlet concentrations of BTEX obtained for FT-0.001 over the 3-h process were 0.87, 0.36, 0.09, and 0.03, respectively; those obtained for P25 TiO₂ photocatalyst were 0.91, 0.82, 0.66, and 0.47, respectively; and those obtained for FT-0 were 0.88, 0.81, 0.58, and 0.41, respectively. It is worth noting that for benzene all of the Fe-TiO₂ composites and the reference TiO₂ photocatalysts produced high comparable ratios of outlet to inlet concentrations. The high ratio of outlet to inlet concentrations values of benzene that translate to a low photocatalytic function were ascribed to lower photocatalytic oxidation rates relative to those displayed by the other three target compounds [31]. Nevertheless, in general, the Fe-TiO₂ composites showed a superior photocatalytic function over the reference TiO₂ photocatalysts for the decomposition of low-concentration aromatic organic pollutants under visible light irradiation. Zhao et al. [32] also reported the superior photocatalytic activity of Fe-TiO₂ composites,

which were synthesized by impregnating Fe(NO₃)₃ solution into anatase phase TiO₂ powder, over TiO₂ powder for the decomposition of 4-nitrophenol in the aqueous phase. The enhanced photocatalytic function of the Fe-TiO₂ composites over the reference TiO₂ photocatalysts was attributed to the presence of Fe³⁺ ions that serve as electron and hole traps ($\text{Fe}^{3+} + \text{e}^- \rightarrow \text{Fe}^{2+}$ and $\text{Fe}^{3+} + \text{h}^+ \rightarrow \text{Fe}^{4+}$), thereby lowering electron-hole recombination rates and consequently enhancing the photocatalytic performance of the composites [18,32]. This was supported by EDX analyses (Fig. 1), which suggest that Fe³⁺ ions are incorporated into the TiO₂ crystal lattice because of the ions' small size (0.064 nm) relative to that of Ti⁴⁺ (0.068 nm) [33].

Figure 7 also shows that the time-series ratios of outlet to inlet concentrations of the following three target chemicals, toluene, ethyl benzene, and *o*-xylene, obtained for the Fe-TiO₂ composites under visible light irradiation increased as the Fe/Ti ratio increased from 0.001 to 0.010. The high outlet to inlet ratios, which reflect a poor photocatalytic activity, were ascribed to excess iron ions that would serve as centers for the electron-hole recombination process [23]. Excess iron species could also generate Fe(OH)²⁺ ions, capable of absorbing incident photons with a wavelength of 290–400 nm, thereby reducing light exposure onto the photocatalyst, and consequently lowering the photocatalytic performance [32]. In addition, the decreasing trend in the BET surface areas observed for the Fe-TiO₂ composites with increasing Fe/Ti ratios (Table 1) correlated to the corresponding high outlet to inlet ratios, which were associated with a low photocatalytic performance.

Figure 8 shows the time-series ratios of outlet to inlet con-

Fig. 8. Time-series ratios of outlet to inlet concentrations of benzene (a), toluene (b), ethyl benzene (c), and *o*-xylene (d) determined for P25 TiO₂, prepared TiO₂ (FT-0), and Fe-TiO₂ composites with varying Fe/Ti ratios under UV irradiation. The legend in (a) applies to all graphs.

centrations of BTEX obtained over the Fe-TiO₂ composites under UV irradiation. In contrast to the results obtained under visible light exposure, the time-series ratios of outlet to inlet concentrations of BTEX using FT-0.001 and FT-0.004 (low Fe/Ti ratios) were similar to those obtained from the reference TiO₂ photocatalysts under UV irradiation. In addition, the time-series ratios of outlet to inlet concentrations of BTEX determined for the Fe-TiO₂ composites with the two highest Fe/Ti ratios (FT-0.007 and FT-0.010) were higher than those obtained from the reference TiO₂ photocatalysts. More specifically, the average ratios of outlet to inlet BTEX concentrations determined for FT-0.010 over the 3-h process were 0.98, 0.87, 0.63, and 0.45, respectively; those obtained for P25 TiO₂ photocatalyst were 0.21, 0.05, 0.04, and 0.03, respectively; and those obtained for FT-0 were 0.22, 0.06, 0.03, and 0.02, respectively. Hence, the Fe-TiO₂ composites would exhibit different dependence of the Fe/Ti ratios on the photocatalytic decomposition efficiency of low-concentration aromatic organic pollutants according to the irradiation sources (visible light or UV).

4. Conclusions

The application of Fe-TiO₂ composites for purification of low-concentration airborne aromatic organic pollutants was herein examined. EDX analysis of the prepared composites demonstrated that Fe ions were impregnated into the TiO₂ crystal lattice. The expected Fe/Ti mass ratios (calculated during synthesis) were consistent with the observed Fe/Ti mass ratios, as determined from EDX analysis. UV-Vis studies indicated that these photocatalysts could be effectively activated under both visible light and UV irradiation. In general, the Fe-TiO₂ composites showed superior photocatalytic performance over the reference TiO₂ photocatalysts for the decomposition of low-concentration aromatic organic pollutants under visible light exposure conditions. Moreover, the Fe-TiO₂ composites would exhibit different dependence of the Fe/Ti ratios on photocatalytic decomposition efficiency of low-concentration aromatic organic pollutants according to the irradiation conditions (visible light or UV). The Fe-TiO₂ with an optimal Fe/Ti ratio could effectively be applied for the purification of

low-concentration aromatic organic pollutants.

Acknowledgements

This work was supported by the National Research Foundation of Korea grant funded by the Korea government (MEST) (No. 2011-0027916).

References

- [1] Leuchner M, Rappenglück B. *Atmos Environ*, 2010, 44: 4056
- [2] de Blas M, Navazo M, Alonso L, Durana N, Gomez M C, Iza J. *Sci Total Environ*, 2012, 426: 327
- [3] Shin S H, Jo W K. *Chemosphere*, 2012, 89: 569
- [4] Billionnet C, Gay E, Kirchner S, Leynaert B, Annesi-Maesano I. *Environ Res*, 2011, 111: 425
- [5] Paz Y. *Appl Catal B*, 2010, 99: 448
- [6] Jo W K, Kang H J. *Chin J Catal* (催化学报), 2012, 33: 1672
- [7] Xin Q, Lin L W. *Chin J Catal* (催化学报), 2013, 34: 401
- [8] Giraudet S, Pré P, Tezel H, Le Cloirec P. *Carbon*, 2006, 44: 2413
- [9] Zheng Y, Pan Z M, Wang X C. *Chin J Catal* (催化学报), 2013, 34: 524
- [10] Henderson M A. *Surf Sci Rep*, 2011, 66: 185
- [11] Nakata K, Ochiai T, Murakami T, Fujishima A. *Electrochim Acta*, 2012, 84: 103
- [12] Bouras P, Stathatos E, Lianos P. *Appl Catal B*, 2007, 73: 51
- [13] Kment S, Kmentova H, Kluson P, Krysa J, Hubicka Z, Cirkva V, Gregora I, Solcova O, Jastrabik L. *J Colloid Interface Sci*, 2010, 348: 198
- [14] Kaur R, Pal B. *J Mol Catal A*, 2012, 355: 39
- [15] Vargas X, Tauchert E, Marin J-M, Restrepo G, Dillert R, Bahnemann D. *J Photochem Photobiol A*, 2012, 243: 17
- [16] Cui L F, Wang Y S, Niu M T, Chen G X, Chen Y. *J Solid State Chem*, 2009, 182: 2785
- [17] Tieng S, Kanaev A, Chhor K. *Appl Catal A*, 2011, 399: 191
- [18] Sun S, Ding J J, Bao J, Gao C, Qi Z M, Yang X Y, He B, Li C X. *Appl Surf Sci*, 2012, 258: 5031
- [19] Debono O, Thevenet F, Gravejat P, Hequet V, Raillard C, Lecoq L, Locoge N. *Appl Catal B*, 2011, 106: 600
- [20] Xagas A P, Androulaki E, Hiskia A, Falaras P. *Thin Solid Films*, 1999, 357: 173
- [21] Azad A-M, Hershey R, Ali S, Goel V. *J Mater Res*, 2010, 25: 1761
- [22] Ghorai T K, Biswas S K, Pramanik P. *Appl Surf Sci*, 2008, 254: 7498

Graphical Abstract

Chin. J. Catal., 2013, 34: 2209–2216 doi: 10.1016/S1872-2067(12)60688-3

Iron-impregnated titania composites for the decomposition of low-concentration aromatic organic pollutants under UV and visible light irradiation

Wan-Kuen Jo*, Joon Yeob Lee
Kyungpook National University, Korea

Time-series ratios of outlet to inlet concentrations of benzene, toluene, ethyl benzene, and *o*-xylene determined using P25 TiO₂, and Fe-TiO₂ composites at varying Fe/Ti ratios (FT-0, FT-0.001, FT-0.004, FT-0.007, and FT-0.010) under visible light irradiation.

- [23] Liu L F, Chen F, Yang F L, Chen Y S, Crittenden J. *Chem Eng J*, 2012, 181-182: 189
- [24] Spurr R A, Myers H. *Anal Chem*, 1957, 29: 760
- [25] Cullity B D, Stock S R. *Elements of X-Ray Diffraction*. 3rd ed. New Jersey: Prentice Hall, 2001. 167
- [26] Jo W K, Kim J T. *J Hazard Mater*, 2009, 164: 360
- [27] Zhu J F, Chen F, Zhang J L, Chen H J, Anpo M. *J Photochem Photobiol A*, 2006, 180: 196
- [28] Cui L F, Huang F, Niu M T, Zeng L W, Xu J, Wang Y S. *J Mol Catal A*, 2010, 326: 1
- [29] Peng T Y, Zhao D, Dai K, Shi W, Hirao K. *J Phys Chem B*, 2005, 109: 4947
- [30] Mozia S, Heciak A, Morawski A W. *J Photochem Photobiol A*, 2010, 216: 275
- [31] Strini A, Cassese S, Schiavi L. *Appl Catal B*, 2005, 61: 90
- [32] Zhao B X, Mele G, Pio I, Li J, Palmisano L, Vasapollo G. *J Hazard Mater*, 2010, 176: 569
- [33] Lu X N, Ma Y F, Tian B Z, Zhang J L. *Solid State Sci*, 2011, 13: 625