

Photodegradation of Sulfamethoxazole with a Recyclable Catalyst

Han Gong and Wei Chu*

Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon 999077, Hong Kong

ABSTRACT: A new photocatalyst was synthesized by heterojunction of commercial CoFe_2O_4 with P25. The degradation of sulfamethoxazole (SMX) with the photocatalyst under UV 350 nm was investigated. The effects of initial target compound concentration, catalyst dosage, and solution pH on the decay performance of SMX were studied. On the basis of the kinetics data, the pseudo-first-order rate constant of SMX decay becomes predictable by using a proposed model in terms of $[\text{SMX}]_0$ and catalyst dosage. Light attenuation was found and analyzed by a linear correlation between k and transmission via a common factor (i.e., the catalyst dosage). The photocatalyst was found to be stable within the pH range of 5.2–8.8. The photocatalyst was proved to be easily separated and recycled, and the photocatalytic activity of the recycled catalyst remained intact after extensive reuse, suggesting that the $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ is a stable and highly efficient catalyst with good potential in real applications.

1. INTRODUCTION

Sulfamethoxazole (SMX, 4-amino-N-(5-methyl-3-isoxazolyl)benzenesulfonamide), a white, odorless, and tasteless antimicrobial agent, is commonly used as the human and veterinary medicine. As human medicine, SMX is used to treat diseases such as middle ear infection, conjunctivitis, bronchitis, urinary tract infection, malaria, toxoplasmosis, and traveler's diarrhea.¹ As veterinary medicine, SMX is used as feed additives to promote growth and weight gain of food animals apart from the application in treating diseases and infections.²

Because of industrial and domestic activities, SMX may end up in bodies of water through various routes such as pharmaceutical effluents, toilet flushing, and excretes with or without proper treatment.³ For example, livestock excretions, including the metabolized residues, may penetrate the soil and reach the groundwater or be washed off from the soil as surface runoff after a rainfall storm.

Traces of SMX have been identified in almost all kinds of surface water and in the effluents of municipal sewage treatment plant.^{2,4–7} In a survey conducted by the United States, SMX was listed as one of the top six most frequently detected compounds.⁸ SMX was detected at 47, 193, and 480 ng/L in Victoria Harbor,⁹ Pearl River,¹⁰ and Germany,¹¹ respectively. In the effluent of sewage treatment plants, SMX was detected at 52.6 and 2000 ng/L in Hong Kong¹² and Germany,¹³ respectively.

Owing to the low biodegradability, SMX can persist in the environment for a long time and thus was categorized as a persistent antibiotic.¹⁴ It has been shown that even low concentration levels of SMX would pose a serious environmental risk by altering microbial community structure via the yielding of antibiotic resistance.¹⁵ Because of its structural similarity to PABA (*para*-aminobenzoic acid, an intermediate in the synthesis of folate by bacteria, plants, and fungi), SMX can prevent normal bacteria from binding PABA with folic acid enzyme and interfere with the synthesis of folic acid, a critical metabolite in DNA synthesis.^{16,17} The existence of SMX in the environment may induce the mutations of some bacteria, thus yielding antibiotic resistance.¹⁸ In addition, SMX can affect the

aquatic ecosystem by inhibiting the life activity of aquatic organisms. For instance, the growth of zooplankton *Ceriodaphnia dubia* and algae *Pinnularia subcapitata* were inhibited when [SMX] reached 0.21¹⁹ and 0.52 mg/L,¹⁹ respectively. Because of its toxicological effects to the environment and thus the potential risk to human health, it is crucial to study an efficient way to degrade SMX.

Titania (TiO_2) is used widely as a photocatalyst in many processes. There are mainly two phases for TiO_2 , i.e., anatase and rutile phases. The former has been confirmed to play the main part in photocatalytic activity owing to its low recombination rate of photogenerated electrons and holes.^{20,21} Besides, it was found that the composite of two phases of TiO_2 performed better.²² Therefore, a high ratio of anatase/rutile would be beneficial for the photocatalytic activity. TiO_2 P25, composed of anatase and rutile crystallites by a typical ratio of 70:30 or 80:20²³ has been developed successfully to maintain a relatively high level of photocatalytic activity by Evonik Degussa Industries. Several researches have verified that TiO_2 P25 is effective in the degradation of SMX.^{24–26} However, it is difficult for P25 to be applied in the practical water treatment because of its high cost and the limitation from being separated from the liquid phase after use. Therefore, how to reuse/recycle the suspended photocatalyst becomes a critical issue.

Magnetic photocatalysts could be effectively recycled by applying an external magnetic field. Therefore, TiO_2 -coated magnetic photocatalysts have attracted great attention in the water treatment industry. CoFe_2O_4 is one potential magnetic material for such an application. In this study, the $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ was therefore synthesized by heterojunction of commercial P25 with CoFe_2O_4 . The degradation performance of SMX by using the photocatalyst and the recycled/spent catalysts were investigated.

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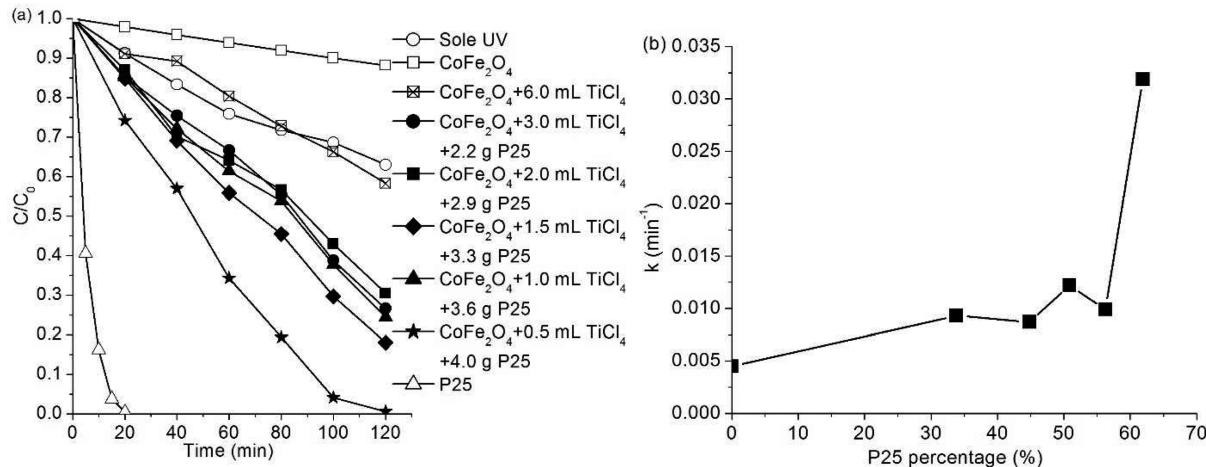


Figure 1. (a) Photocatalytic activity of catalysts with different processes. (b) Decay rate constant as a function of P25 percentage. Experimental condition: $[\text{SMX}]_0 = 0.02 \text{ mM}$, catalyst dosage = 1.0 g/L, 12 350 nm UV lamps were employed.

2. MATERIALS AND METHODS

2.1. Materials. SMX ($\text{C}_{10}\text{H}_{11}\text{N}_3\text{O}_3\text{S}$) was purchased from Wako Pure Chemical Industries, Japan. CoFe_2O_4 (30 nm with high purity of 99.9%) was purchased from US Research Nanomaterials Inc., and P25 was purchased from Degussa. Other chemicals, including titanium tetrachloride (TiCl_4), potassium phosphate monobasic (KH_2PO_4), orthophosphoric acid (H_3PO_4), hydrochloric acid (HCl), and sodium hydroxide (NaOH) were obtained from Sigma-Aldrich Inc., USA, and are of analytical grade. The mobile-phase solvent (i.e., acetonitrile) is of HPLC grade and was purchased from Tedia Company, USA. All solutions were prepared in ultrapure water from a Barnstead NANO pure water system (Thermo Fisher Scientific Inc., USA).

2.2. $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ Synthesis. The synthesis of $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ photocatalyst was modified from the method reported by Gao et al.²⁷ First, 2.1 g of CoFe_2O_4 and a certain dosage of TiCl_4 were introduced in 200 mL of ultrapure water. The pH value of the solution was adjusted to 9–10 with ammonia under mechanical stirring at 15 °C for 1 h, during which P25 was added into the solution stepwise. Then, the obtained particles were washed with ultrapure water three times, and the obtained particles were dried in a vacuum-drying oven at 80 °C for 48 h.

The phase of magnetic photocatalysts $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ was characterized by the X-ray diffraction technique. The XRD analysis was carried out on an X-ray diffractometer (Smartlab) with Cu K α radiation ($\lambda = 0.1540 \text{ nm}$) employing a scan rate (2θ) of 5°/min ranging from 20 to 80°. The accelerating voltage and the applied current were 15 kV and 20 mA, respectively.

2.3. SMX Degradation Procedures. The UV-induced photocatalytic reaction was carried out in a Rayonet RPR-200 photochemical reactor containing 12 phosphor-coated low-pressure mercury lamps (350 nm) at room temperature (air-conditioned), i.e., 23 ± 1 °C. To ensure a thorough mixing, 150 mL of solution was dispensed into a 300 mL quartz cylinder and mixed with a nonmetal mechanical stirrer before and during the illumination. To exclude the effect of adsorption on the degradation, the predetermined amount of $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ was added into 150 mL of SMX solution and stirred mechanically in darkness for 30 min to achieve adsorption equilibrium. Then, the reaction was started by turning on the

lamps. At preset intervals, 1 mL of sample was withdrawn and filtered through a 0.22 μm membrane filter (ADVANTEC HP020AN, Japan) for further analysis. The recovery of SMX after the filtering was determined to be around 100%. All experiments were conducted in duplicate, and the error is less than 5%.

2.4. Analysis. The SMX concentration was measured with a high-performance liquid chromatograph (HPLC), equipped with a Waters 2489 Dual Absorbance Detector, a Waters 515 HPLC pump, a Waters 717 plus Autosampler, and a Restek C18 column (5 μm , 4.6 × 250 mm²). The absorption wavelength at 263 nm was selected to quantify the SMX concentration. The mobile phase was a mixture of 50% acetonitrile and 50% 5 mM KH_2PO_4 , the pH level was adjusted to 3.0 with H_3PO_4 , and the flow rate was 1 mL/min. The pH level was measured with a digital pH meter (model: HANNA instrument, B417). A Total Organic Carbon (TOC) analyzer (shimadzu, TOC-L) was used to measure TOC.

3. RESULTS AND DISCUSSION

3.1. Photocatalytic Activity of Catalysts with Different Processes.

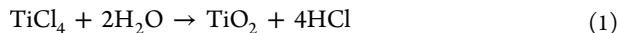
There are different ways to synthesize $\text{CoFe}_2\text{O}_4/\text{TiO}_2$, and TiO_2 was mostly synthesized via the hydrolysis of titanium butoxide ($\text{Ti}(\text{C}_4\text{H}_9\text{O})_4$) or titanium tetrachloride (TiCl_4). The phase structure of synthesized TiO_2 and thus the photocatalytic activity can be changed by calcination.²⁸ Though the catalysts synthesized on the basis of the above process proved efficient in the degradation of some dyes, e.g., methyl blue,²⁹ unfortunately the same process was tested and proved inefficient in the degradation of SMX in this study (data not shown). By doping P25 to CoFe_2O_4 in the assistance of forming fresh TiO_2 during the synthesis was therefore investigated.

Processes with different dosages of TiCl_4 were carried out to investigate the best dosages of TiCl_4 and P25. The photocatalytic activity of the synthesized catalysts, solely CoFe_2O_4 , and P25 is shown in Figure 1. It was found that all the decay curves followed pseudo-first-order kinetics.

It was surprising that only about 10% SMX was removed by CoFe_2O_4 (in the presence of UV) at the end of the reaction, which is even lower than that by using solely UV (about 40% removal). This is because CoFe_2O_4 has a lower photocatalytic activity in the degradation of SMX, and the particle of CoFe_2O_4

blocks the photons' path, which inhibits the direct photolysis of the UV. (The transmission of the solution with CoFe_2O_4 is 48.2% lower than that without the catalyst.) When TiCl_4 was added, however, the removal efficiency was significantly improved, compared to that of solely CoFe_2O_4 . These observations suggest that both direct photolysis and photocatalysis coexist in the process.

The accelerated reaction compared to that with solely CoFe_2O_4 is attributed to the formation of TiO_2 via the hydrolysis of TiCl_4 , as follows:



The TiO_2 formed on the surface of CoFe_2O_4 core can be calculated stoichiometrically according to eq 1. The required P25 (added separately) makes up the difference and ensures that the same overall TiO_2 in the composite photocatalyst can then be estimated. The result shows that the photocatalytic activity of the synthesized catalysts increases largely with the addition of P25. About 75% SMX was removed at the end of the reaction with the catalyst synthesized by the mixture of 3 mL of TiCl_4 and 2.2 g of P25, i.e., 34% P25, in the composite. The introduction of TiCl_4 and P25 at different dosages contributes to different ratios of anatase and rutile and thus the different degradation efficiency. In general, the higher the percentage of P25, the faster the reaction rate, as shown in Figure 1b. At 62% P25, the SMX was completely removed in 120 min, indicating that P25 played the main role in the photocatalysis. This can be evidenced by the good degradation efficiency with pure P25, where all the SMX was removed in 20 min; however, it should be noted that this is not a fair test because the pure P25 has much smaller particle size than that of synthesized magnetic catalyst at the same dosage. In addition, the newly synthesized TiO_2 via hydrolysis is mainly functioning as an adhesive to bond the CoFe_2O_4 core and the P25 together. It is reasonable for the synthesized TiO_2 to have fewer active sites or a smaller surface area for the reaction.

Though the reaction rate increases continually with the increase of P25 dosage, the further increase of the P25 percentage will make the free dispersion of P25 to the core surface difficult, likely because of the deficiency of the adhesive, i.e., fresh TiO_2 , as discussed before. Alternatively, if the dosage of TiCl_4 and P25 were increased simultaneously and the dosage of CoFe_2O_4 kept unchanged, then the resulting catalyst will no longer be magnetic. Therefore, the catalyst used in the following study was synthesized with 2.1 g of CoFe_2O_4 , 0.5 mL of TiCl_4 , and 4.0 g of P25, under optimal conditions.

3.2. XRD. To verify the component of the synthesized catalyst, the X-ray diffraction pattern of the prepared composite is shown in Figure 2. The peaks of CoFe_2O_4 and TiO_2 anatase phase and rutile phase in the $\text{CoFe}_2\text{O}_4/\text{TiO}_2$ composite were clearly observed. According to the standard diffraction patterns (Joint Committee on Powder Diffraction Standards (JCPDS)), the main characteristic peaks of CoFe_2O_4 (Powder Diffraction File (PDF) no. 22-1086, JCPDS, 1995)³⁰ observed at $2\theta = 29.9, 35.2, 36.2, 42.8, 56.6$, and 62.3° are well-indexed to the crystal planes of CoFe_2O_4 at (220), (311), (222), (400), (511), and (440), respectively. Besides, the peaks appearing at $25.2, 37.8, 48.1, 54.8$, and 62.6° , corresponding to anatase TiO_2 (PDF no. 21-1272, JCPDS, 1995)³¹ at (101), (004), (200), (105), and (204), and the peak at 27.4° for the characteristic reflection of rutile TiO_2 (PDF no. 21-1276, JCPDS, 1995)³² can also be observed in Figure 2. The crystal structure of CoFe_2O_4 , anatase TiO_2 , and rutile TiO_2 in the new composite

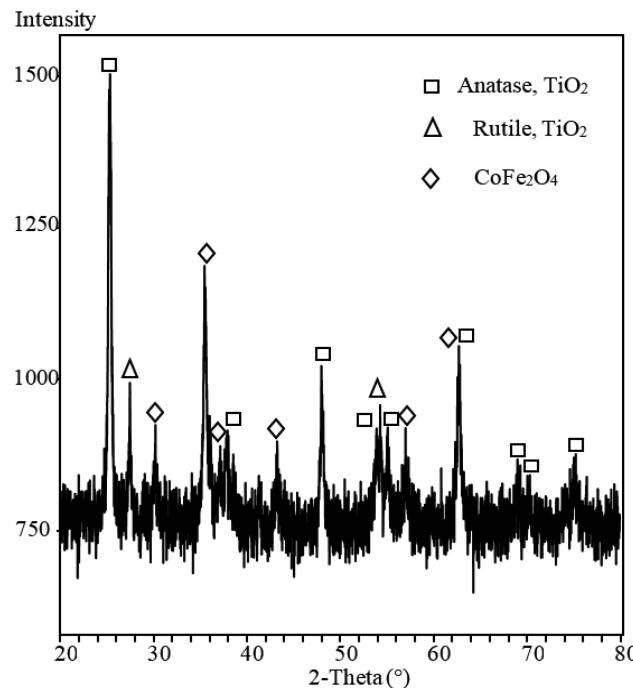


Figure 2. XRD pattern of $\text{CoFe}_2\text{O}_4/\text{TiO}_2$.

is as same as those in their original structure. No peaks were found other than the peaks of CoFe_2O_4 and TiO_2 anatase phase and rutile phase. Therefore, no phase change of the crystal structure was caused, and no new substance formed in the preparation process. The introduction of Cl^- and NH_4^+ due to the addition of TiCl_4 and $\text{NH}_3\cdot\text{H}_2\text{O}$ was apparently washed away during the preparation, which guarantees the purity of the material and excludes the effect of inorganic ions on the degradation.

3.3. Effect of Initial Concentrations of SMX and Catalyst Dosage. The effect of initial concentrations of SMX ($[\text{SMX}]_0$) was examined in the photocatalytic process. It is indicated that lower initial concentration results in higher removal efficiency. The final removal efficiency at 100 min increased from 40 to 99% as $[\text{SMX}]_0$ decreased from 0.2 to 0.005 mM (Figure 3a). In this study, because the UV intensity is constant, the increase of $[\text{SMX}]_0$ will make the solution change from optically dilute to optically dense. The deficiency of photons of the latter case is the reason contributed to its lower degradation efficiency. A linear correlation between k and $\ln [\text{SMX}]_0$ can be established as shown in Figure 3b.

In Figure 4, the SMX decay performance was investigated as the catalyst dosage varying from 0 to 2.0 g/L. Only about 20% SMX was removed under the irradiation of UV without using the photocatalyst. After introducing the photocatalyst, the reaction rate enhanced significantly. The final removal increased from about 20 to 94% as the dosage of catalyst increased from 0 to 0.5 g/L. After the optimal dosage at 0.5 g/L, further increase of the dosage will retard the reaction. This is likely ascribed to the reduction in the light penetration resulting from the abundance of catalyst particles. This light attenuation effect was justified in Figure 4c, in which the transmission decreased significantly with the increase of the catalyst dosage. It is also interesting to note that in the dosage range of 0.5–2.0 g/L, two linear correlations between k and catalyst dosage, and transmission and catalyst dosage were identified. Therefore, a liner correlation between the k and transmission is established

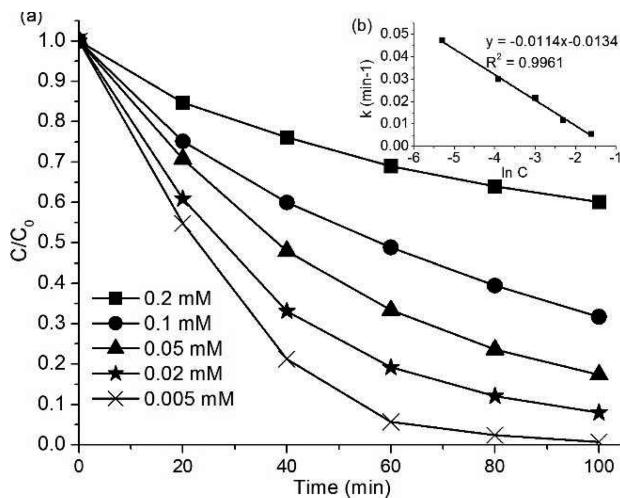


Figure 3. (a) Effect of initial concentration of SMX on the photodegradation. (b) Decay rate constant as a function of initial concentration of SMX. Experimental condition: catalyst dosage = 1.0 g/L, 12 350 nm UV lamps were employed.

and justifies well the light attenuation assumption. The catalyst dosage at 0.5 g/L was determined as the optimum dosage for the catalyst in this process, in which SMX was completely degraded in 50 min.

According to the linear correlations of \$k\$ and \$[\text{SMX}]_0\$ (Figure 3b), as well as \$k\$ and catalyst dosage (Figure 4b in the range of 0.5–2.0 g/L), the pseudo-first-order rate constant (\$k\$, \$\text{min}^{-1}\$) of SMX decay becomes predictable in terms of \$[\text{SMX}]_0\$ and catalyst dosage. By using multiregression technique, a prediction model is shown in eq 2

$$\begin{aligned} k = & 4.47 \times 10^{-4} [\text{CoFe}_2\text{O}_4/\text{TiO}_2] \\ & - 1.34 \times 10^{-2} \ln [\text{SMX}]_0 - 1.53 \times 10^{-2} \\ & (R^2 = 0.7504) \end{aligned} \quad (2)$$

3.4. Effect of pH. Because the pH level plays an important role in the degradation process, six pH levels ranging from 2.2 to 10.8 were investigated in this study. Because the \$pK_{a1}\$ and \$pK_{a2}\$ were \$1.85 \pm 0.30\$ and \$5.60 \pm 0.04\$, respectively,³³ the test was conducted at

- 1) pH 2.2, a point at which pH \$\approx pK_{a1}\$;
- 2) pH 3.6 and 5.2, two points between \$pK_{a1}\$ and \$pK_{a2}\$;

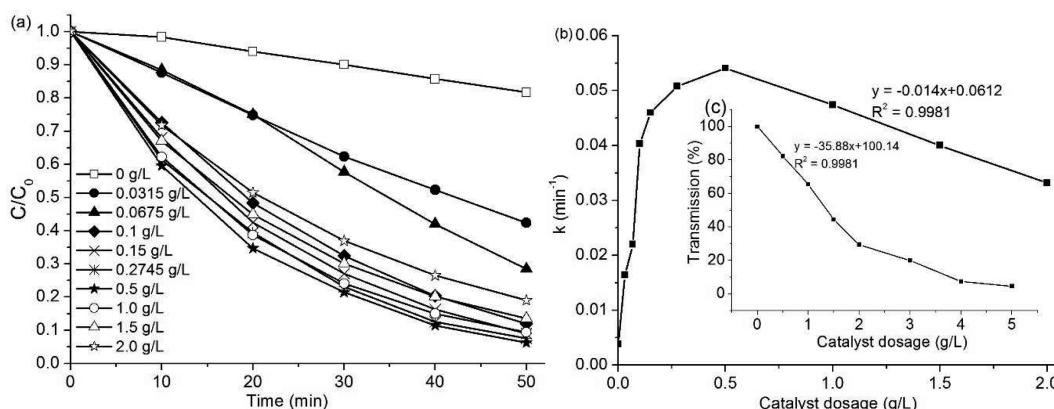


Figure 4. (a) Effect of catalyst dosage on the photodegradation. (b) Decay rate constant as a function of catalyst dosage. (c) Transmission as a function of catalyst dosage. Experimental condition: \$[\text{SMX}]_0 = 0.005\$ mM, 12 350 nm UV lamps were employed.

3) pH 6.8, 8.8, and 10.8, three points above \$pK_{a2}\$.

The results are shown in Figure 5, in which the fastest reaction occurred at pH 2.2, 96% of SMX was removed in 5

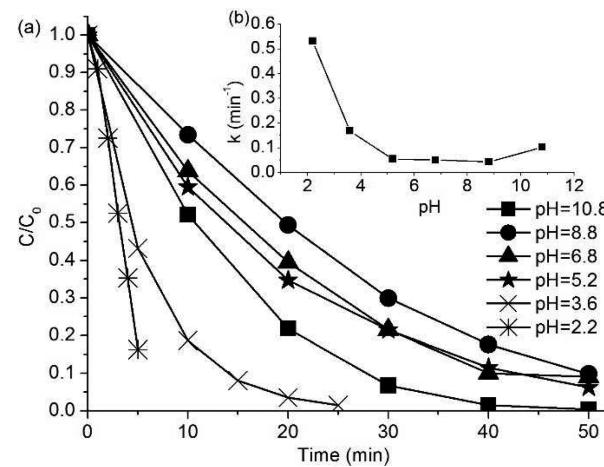


Figure 5. (a) Effect of pH of SMX on the photodegradation. (b) Decay rate constant as a function of pH. Experimental condition: \$[\text{SMX}]_0 = 0.005\$ mM, catalyst dosage = 0.5 g/L, 12 350 nm UV lamps were employed.

min, and followed by pH 3.6 and 10.8. However, it was observed that the catalyst became unstable at these extreme pH levels. That is, at pH 2.2, 3.6, and 10.8, some white/milky substance leached out to the solution. To understand the mechanism of the fast reactions at these extreme pH levels, a series of tests were conducted.

The possible adsorption and hydrolysis contributed to the degradation of SMX at extreme pH levels were examined first. The results are shown in Figure 6a, where 30 to 0 min is the preadsorption for equilibrium as mentioned in the methodology. It was found that the processes of adsorption and hydrolysis were insignificant. Therefore, the fast reaction at pH levels 2.2, 3.6, and 10.8 was not due to the additional adsorption nor hydrolysis.

The white substance that leached out to the solution was examined next. After the adsorption reached the equilibrium, the catalyst was removed by a magnet, and the milky solution was used to react with the SMX under the UV. The result shown in Figure 6b indicated that the degradation curve was

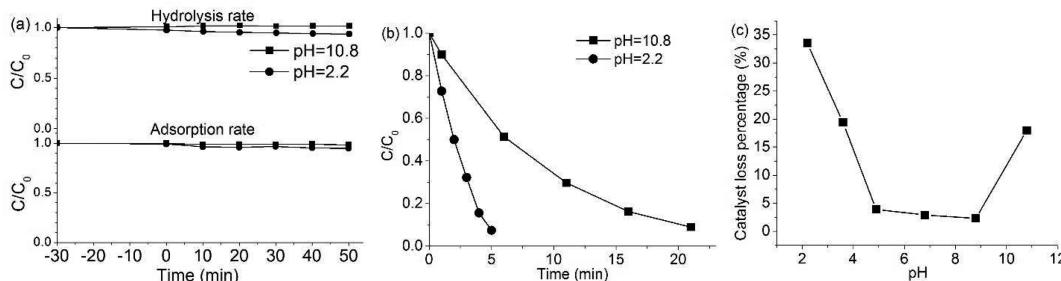


Figure 6. (a) Hydrolysis rate and adsorption rate during the photodegradation. (b) Degradation of sulfamethoxazole under leaching TiO₂. (c) Catalyst leaching dosage. Experimental condition: [SMX]₀ = 0.005 mM, catalyst dosage = 0.5 g/L, 12 350 nm UV lamps were employed.

similar to that shown in Figure 5a. This suggests that the fast reaction at extreme pH levels was mainly due to the leaching of TiO₂/P25 from the catalyst surface.

The mass of leached TiO₂ was determined by paper filtration after drying; the percentage of leached TiO₂ was shown in Figure 6c. It was found that, about 35 and 20% of TiO₂ leached from the catalyst at pH 2.2 and 10.8, respectively. The higher the leaching of TiO₂, the higher the removal efficiency. This leaching pattern (Figure 6c) is even similar to that of the reaction rate (Figure 5b); thus, this similarity of pattern reconfirms the contribution of leached TiO₂ to the enhanced reaction rate at extreme pH levels. However, it should be noted that very low (2–3%) or no TiO₂ leaching was observed at pH levels ranged from 5.2 to 8.8. (In fact, the observed low level mass loss in Figure 6a may due to the imperfect filtration and drying process.) Therefore, the synthesized catalyst is considered to be very stable at neutral pH range for real application.

Within the pH range of 5.2–8.8, the best pH for the process is at pH 5.2. Increasing pH from 5.2 to 8.8 causes a small drop in removal efficiency. At pH 5.2, most of the SMX exists in the neutral state^{34,35} and has stronger light absorption,²⁵ resulting in a higher degradation efficiency. When the pH level is higher than pK_{a2} (5.6), most of the SMX becomes a negatively charged conjugate base, and strong oxidants such as hydroxyl radical generally have a lower affinity to react with the negatively charged compound,^{34–36} leading to a lower degradation efficiency.

The pH change during the process of adsorption (time before 0) and photocatalytic reaction (time after 0) is shown in Figure 7. In the process of adsorption, pH dropped when the initial pH level is 8.8 and above, whereas the pH increased slightly and had no significant change at neutral (6.8–5.2) and acidic (3.6–2.2) conditions, respectively. It suggests that the surface of CoFe₂O₄/TiO₂ is close to neutral. During the photocatalytic reaction, a significant pH drop occurred when the initial pH level is high. The pH drop is likely due to the formation of CO₂ and low-molecular-weight organic acids from the decay of SMX. Given the fact that H₂CO₃ is a weak acid with pK_a's at 6.3 and 10.3, the H⁺ released to the solution was not sufficient to change the solution pH when the initial pH level was in the neutral to acidic range; therefore, a relatively stable pH was observed.

In practice, the removal of SMX at extremely low or high pH is not recommended. Therefore, pH of 5.2 was selected for further study; thus, no pH adjustment is required in SMX removal.

3.5. Photocatalytic Activity of Recycled Catalyst and Mineralization.

Because the advantage of using the composite

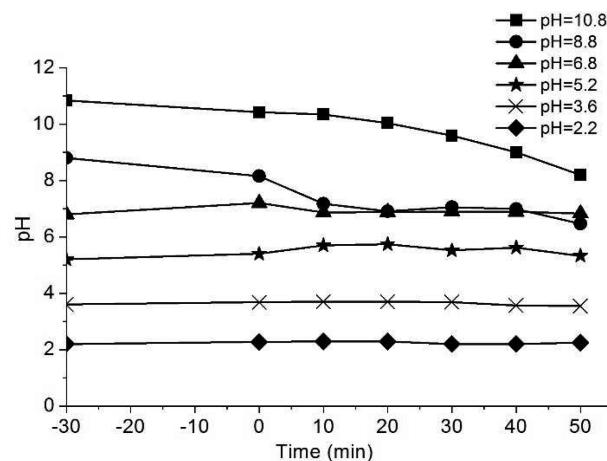


Figure 7. Change of pH value during the photodegradation. Experimental condition: [SMX]₀ = 0.005 mM, catalyst dosage = 0.5 g/L, 12 350 nm UV lamps were employed.

photocatalyst is the association of magnetic and photocatalytic properties, it is necessary to evaluate the recycling efficiency of the catalyst, including whether the catalysts can be recycled easily without significant mass loss and whether the recycled catalyst can maintain its performance in reaction after several runs of usage.

First, the magnetic activity was evaluated with the result shown in Figure 8, where the photos show the CoFe₂O₄/TiO₂

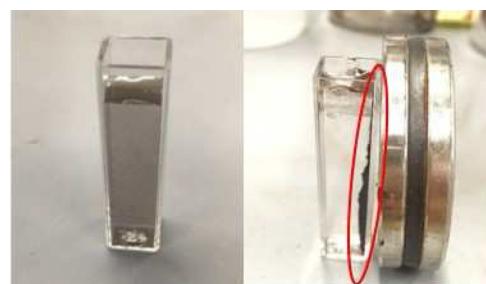


Figure 8. Separation of CoFe₂O₄/TiO₂ from the treated SMX solution.

photocatalyst suspended in the SMX solution with and without the magnetic field. The separation process is thorough and fast; it only takes 1–2 s to collect almost all the spent photocatalyst.

The photocatalytic activity of the recycled catalyst was also determined. After each photocatalytic reaction, the catalyst was separated, collected and washed with ultrapure water, then dried at 80 °C. The weight loss during the tests was determined

to be less than 5%. It should be noted that the washing and drying of spent catalyst are not necessary in real applications, so that the mass loss in practice should be much lower than 5%. After five rounds of recycling, the performance of the reused catalyst in degrading SMX was shown in Figure 9, in which the

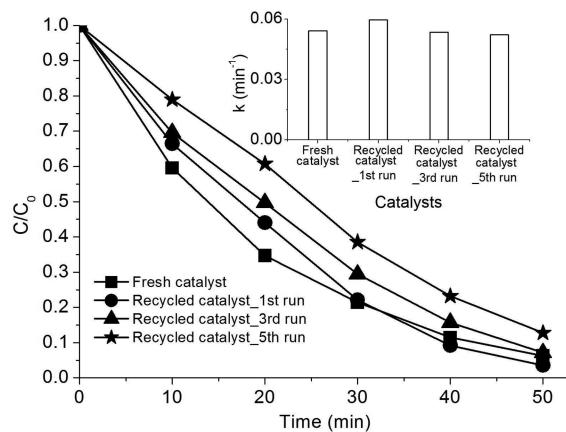


Figure 9. (a) Degradation efficiency of recycled catalysts. (b) Decay rate constant of photodegradation under recycled catalysts. Experimental condition: $[SMX]_0 = 0.005$ mM, catalyst dosage = 0.5 g/L, 12 350 nm UV lamps were employed.

photocatalytic activity of the recycled catalyst is similar to that of the fresh catalyst without noticeable degradation. This demonstrates that the photocatalytic activity of synthesized $CoFe_2O_4/TiO_2$ is very stable. Given the magnetic and stable photocatalytic properties, the $CoFe_2O_4/TiO_2$ catalyst should have good application prospects in water/wastewater treatment.

The ability of the photocatalyst in the SMX mineralization was also tested by measuring the TOC variation during the degradation process. The initial SMX concentration was adjusted to 0.05 mM to increase the accuracy of TOC analysis. From Figure 10, the photodegradation was also effective in TOC removal. About 50% TOC was eliminated when 95% SMX was decomposed.

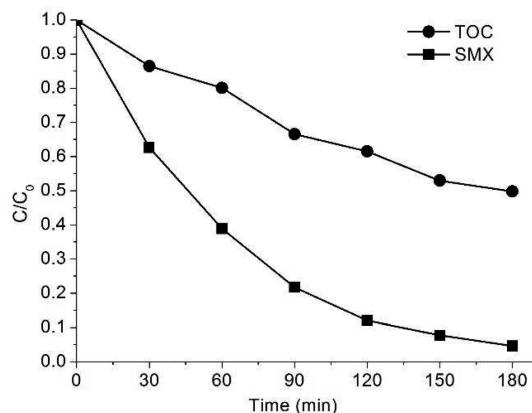


Figure 10. Removal of TOC during SMX degradation by UV/ $CoFe_2O_4/TiO_2$. Experimental condition: $[SMX]_0 = 0.05$ mM, catalyst dosage = 0.5 g/L, 12 350 nm UV lamps were employed.

4. CONCLUSIONS

In this study, a magnetic $CoFe_2O_4/TiO_2$ photocatalyst was synthesized. Its photocatalytic activity was evaluated by the degradation of SMX. The effects of initial target compound concentration, catalyst dosage, and solution pH levels on the decay performance and reaction kinetics were explored. The ability of the photocatalyst in SMX mineralization was evaluated. The SMX degradation was found to have pseudo-first-order kinetics, and the observed rate constant (k , min⁻¹) is predictable by a proposed model in terms of the $[CoFe_2O_4/TiO_2]$ and $[SMX]_0$, where the working catalyst dosage was 0.5–2.0 g/L with the optimal pH at 5.2. The photocatalyst was found to be stable within the pH range of 5.2–8.8, whereas TiO_2 leaching would only occur in an extremely acidic or alkali environment. Sulfamethoxazole was almost completely removed in 50 min, and about 50% TOC was eliminated at 0.5 g/L $CoFe_2O_4/TiO_2$ at pH 5.2. The recycling tests proved that the photocatalyst was easily separated and that the photocatalytic activity of the recycled catalyst remains intact even after five rounds of reuse, suggesting that the $CoFe_2O_4/TiO_2$ catalyst has good performance in real applications.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: cewchu@polyu.edu.hk.

Notes

The authors declare no competing financial interest.

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