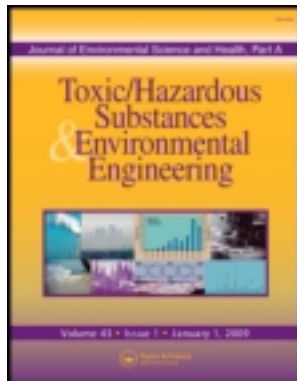


This article was downloaded by: [National Chiao Tung University 國立交通大學]

On: 27 April 2014, At: 20:39

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/lesa20>

Heterogeneous Photocatalytic Oxidation of Acetone for Air Purification by Near UV-Irradiated Titanium Dioxide

Chiu-Ping Chang^{a,b}, Jong-Nan Chen^a & Ming-Chun Lu^c

^a Institute of Environmental Engineering, National Chiao Tung University, Hsinchu, Taiwan, ROC

^b Department of Environmental Engineer and Health, Yuanpei Institute of Science and Technology, Hsinchu, Taiwan, ROC

^c Department of Environmental Engineer and Health, Chia Nan University of Pharmacy and Science, Tainan, Taiwan, ROC

Published online: 06 Feb 2007.

To cite this article: Chiu-Ping Chang, Jong-Nan Chen & Ming-Chun Lu (2003) Heterogeneous Photocatalytic Oxidation of Acetone for Air Purification by Near UV-Irradiated Titanium Dioxide, Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering, 38:6, 1131-1143, DOI: [10.1081/ESE-120019869](https://doi.org/10.1081/ESE-120019869)

To link to this article: <http://dx.doi.org/10.1081/ESE-120019869>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>



JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH
Part A—Toxic/Hazardous Substances & Environmental Engineering
Vol. A38, No. 6, pp. 1131–1143, 2003

Heterogeneous Photocatalytic Oxidation of Acetone for Air Purification by Near UV-Irradiated Titanium Dioxide

Chiu-Ping Chang,^{1,2,*} Jong-Nan Chen,¹ and Ming-Chun Lu³

¹Institute of Environmental Engineering, National Chiao Tung University, Hsinchu, Taiwan, ROC

²Department of Environmental Engineer and Health, Yuanpei Institute of Science and Technology, Hsinchu, Taiwan, ROC

³Department of Environmental Engineer and Health, Chia Nan University of Pharmacy and Science, Tainan, Taiwan, ROC

ABSTRACT

This work presents a photocatalysis-based method to treat and purify air because of its broad applicability to common, oxidizable air contaminants. The effect of oxygen content, temperature, water vapor, and acetone concentration on the photooxidation of acetone on TiO₂ surface was investigated. The photocatalytic decomposition reaction of acetone obeyed the first-order equation. The decomposition rate increased with increasing the oxygen content. The rate of acetone oxidation increased when water vapor increased from 18.7 to 417 μM and decreased at higher than 417 μM. The conversion and mineralization of acetone decreased at higher than 138°C. The initial rate of acetone degradation can be well described by the Langmuir–Hinshelwood rate form. The specific reaction rate constant and the equilibrium adsorption are 15.8 μM/min and 0.0671 L/μM, respectively. The difference between observed and estimated half-lives became larger when the initial concentration of acetone was increased. It is

*Correspondence: Chiu-Ping Chang, Department of Environmental Engineering and Health, Yuanpei University of Science and Technology, 306, Yuanpei St., Hsinchu, Taiwan 300, ROC; E-mail: changcp@mail.yust.edu.tw.



assumed that the intermediates competed with parent compound so that delayed the half-life. The detection of CO_2 production can support this assumption.

Key Words: Acetone; Photocatalysis; Titanium dioxide; Langmuir–Hinshelwood equation; Kinetics; Intermediate competition.

INTRODUCTION

The photocatalyzed oxidative removal of trace contaminants from air is a growing research area. Attractive advantages are that this process operation at ambient temperature and pressure, use of molecular oxygen as the oxidant and final oxidation products that are usually innocuous. The photocatalytic oxidation of single compound feeds has been previously demonstrated for alkanes,^[1] alkenes,^[2] alcohols,^[3–6] ketone,^[7–10] aromatics,^[10–12] halogenates,^[13–15] and inorganics.^[16]

Volatile organic compounds (VOCs) containing organic carbon can be vaporized at significant rates. Some are toxic and carcinogenic, and are regulated individually as hazardous pollutants. The serious problem related to the emission of VOCs is that they participate in the photochemical reaction and also in the formation of photochemical oxidants; for example, ozone and peroxyacetyl nitrate.^[17]

Acetone is a common chemical used extensively in a variety of industrial and domestic application. For example, the printing industry and analytical laboratories use frequently acetone as a solvent; it is a principal constituent of many common household chemicals.^[18] Very high concentration of acetone has been detected in indoor and outdoor air environment.^[19] Photocatalytic oxidation of gaseous acetone was discussed recently.^[7–10,18,20–22] Peral and Ollis^[10] reported that the rate of acetone oxidation follows the Langmuir–Hinshelwood equation. No reaction intermediates were detected for acetone oxidation at conversions of 5–20%. Other studies^[9,18,24] also showed that no reaction intermediates were observed in those experiments. In contrast, Larson et al.^[25] reported the generation of a surface intermediate before complete acetone oxidation. Xu and Raftery^[22] used in situ solid-state nuclear magnetic resonance spectroscopy to study acetone of photocatalytic oxidation. The surface intermediates included diacetone alcohol, mesityl oxide, formic acid, propylene oxide, and acetic acid. In a batch photo-reactor, the water vapor inhibited the degradation of acetone from 0 to 0.75 mol/m^3 .^[23] In addition, temperature is a key parameter for the oxidation of organic vapors. The rate of acetone oxidation in the photocatalytic system can reach a maximum value at 80°C . A variation of the photocatalyst color with temperature has also been observed. After the operation at 120°C , the color was yellow, and became brown when the reaction temperature is 163°C .^[26] Vorontsov et al.^[8] also observed that the rate of the acetone oxidation reached a peak at about 100°C .

However, the literatures mentioned above did not use the CO_2 production to evaluate the mineralization efficiency. In this study, therefore, a batch reactor under UV light was applied for the photocatalytic degradation rate as a function of the

initial concentration of acetone, water vapor, temperature, and oxygen content. A thin film of TiO_2 was coated on the internal surface of a glass tube where carried out the photocatalytic reaction. The kinetic of photocatalytic degradation of acetone in the gas-phase on TiO_2 was investigated in detail. The disappearance kinetic of acetone was corresponded with a pseudo-first-order equation. The Langmuir–Hinshelwood kinetic was used to describe the heterogeneous gas-solid reaction.

MATERIALS AND METHODS

A batch reactor made of Pyrex glass is represented in Fig. 1. The annular reactor was fabricated from glass. The width of the annulus was 15 mm to 18.5 mm and the length was 300 mm. The total volume of reactor was 110 cm^3 . Illumination was provided by a 10 W black light lamp (Sankyo Denki Japan-BLB) with a maximum light intensity output at 365 nm. Acetone and water were draw by syringes to stainless steel tube and wrapped with heating tape for vaporization. The concentration of acetone and water were controlled by the syringe pumps (KD Scientific, Model 250). The mass flow controller (MKS, Model 247C) controlled the flow rate of nitrogen and oxygen. The reactor was wrapped with heating tape to maintain the temperature of reaction.

TiO_2 powder was obtained from Degussa (P-25) with a primary particle diameter of 30 nm, a crystal structure of primarily anatase and a surface area of $50 \pm 15 \text{ m}^2/\text{g}$ (BET). The catalyst was used without pretreatment. The TiO_2 was coated on the outer surface of inner tube using a well mixed slurry of 10 wt% TiO_2 in deionized water. The area of catalyst film was 52 cm^2 . The TiO_2 -coated tube was heated at 110°C for 1.5 h.

A typical experiment followed the steps. First, closed the valves at the two side of reactor if the concentration of acetone stabilized. Additionally, turned on the

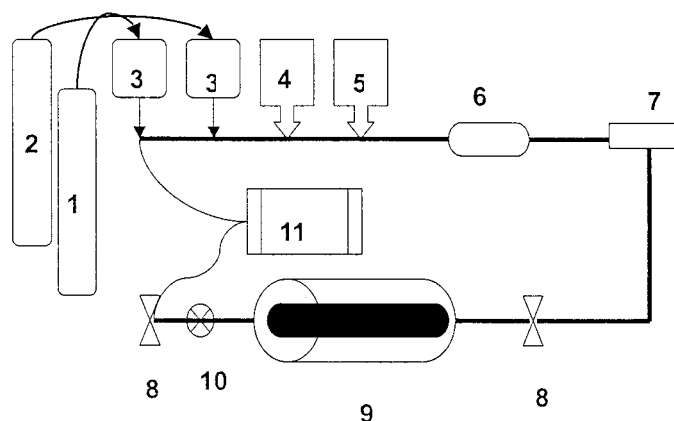


Figure 1. Setup of experimental apparatus. 1. N_2 cylinder; 2. O_2 cylinder; 3. mass flow controller; 4. syringe—acetone; 5. syringe—water; 6. mixer; 7. detector of dewpoint; 8. valve; 9. photocatalytic reactor; 10. sampling pore; 11. temperature controller.



UV lamp then turned off the lamp after one minute. Whereas, inserted a 20 mL syringe into sampling pore to adequately mix the gas in the reactor. Then, used gastight syringe to sample from the sampling pore. Finally, repeated step 2–4 until the reaction completed.

Reaction samples were analyzed by a China GC-9800F gas chromatograph equipped with a flame ionization detector (FID). A porapak Q packed column (1 m long \times 1/8 inch o.d.) was employed to analyze the concentration of acetone. Nitrogen was used as the carrier gas. Carbon dioxide formed as a result of acetone photooxidation was analyzed with an FID and a porapak N column (2 m long \times 1/8 inch o.d.) after converting CO_2 to CH_4 through a Ni-catalyst methanizer. The temperature of porapak N column and methanizer was 60°C and 370°C , respectively.

RESULTS AND DISCUSSION

Effect of Initial Concentration

The effect of initial acetone concentration on degradation rate is exemplified by Fig. 2 when temperature was 138°C , oxygen content was 20%, and water vapor was $18.7\ \mu\text{M}$. The remaining concentration is a function of the reaction time. The photocatalytic decomposition reaction follows a first-order expression (Eq. (1)).

$$r = -\frac{dC}{dt} = k_{\text{app}} C \quad (1)$$

where r is the reaction rate for the oxidation of acetone, C is the concentration of acetone at the reaction time (t) and k_{app} is the apparent rate constant.

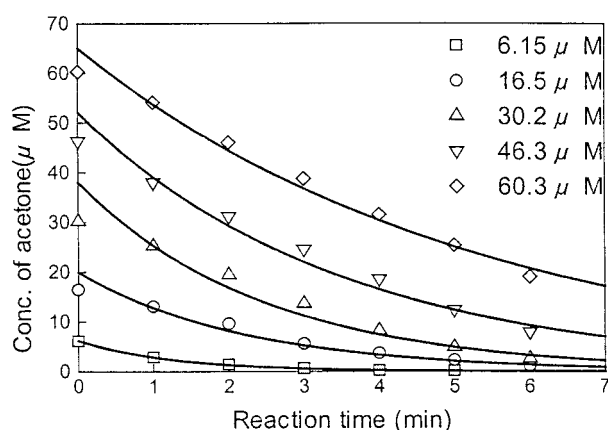


Figure 2. Effect of acetone concentration on photocatalytic degradation (Experimental condition: temperature = 138°C ; oxygen = 20%; water vapor = $18.7\ \mu\text{M}$; acetone conc. = $11.4\ \mu\text{M}$).



Oxidation of Acetone

1135

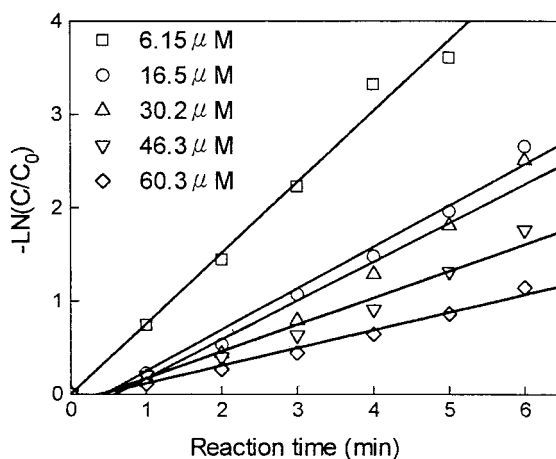


Figure 3. Kinetics for acetone in photocatalytic degradation.

Table 1. Comparison of apparent rate constants k_{app} , $t_{1/2}$, and $t_{1/2}^*$ for the photodegradation of acetone at different initial concentrations.

C_i (μM)	k_{app} (1/min)	r ($\mu\text{M}/\text{min}$)	$t_{1/2}$ (min)	$t_{1/2}^*$ (min)	Mole of CO_2 produced/ mole of acetone degraded
6.15	0.759	4.67	0.92	0.85	2.79
16.5	0.444	7.33	2.00	1.18	2.10
30.2	0.407	12.3	2.27	1.61	2.12
46.3	0.287	13.3	2.82	2.12	1.69
60.3	0.190	11.5	4.04	2.56	1.48

The integrated form of Eq. (1) is

$$-\ln \frac{C}{C_0} = k_{app} t \quad (2)$$

This relationship between $-\ln(C/C_0)$ and reaction time is linear. The slope of the line is the apparent rate constant, k_{app} , shown in Fig. 3. Table 1 lists k_{app} , initial reaction rate (r) and half-life values ($t_{1/2}$) of the photodegradation of acetone as a function of initial concentration. It is obvious that the rate increased with increasing initial concentration of acetone. The rate of photocatalytic oxidation was controlled by adsorption of reactant and desorption of product. The adsorption of reactant was the limiting-rate step at low concentration. Increasing the concentration of acetone increased the adsorption of reactant on TiO_2 surface. Hence, the oxidation rate increased with increasing the concentration of acetone. On the other hand, the amount of adsorption was limited by adsorption site on TiO_2 surface. Increasing the concentration of acetone could not add the amount of adsorption at high concentration. Desorption of product became the limiting-rate step.



Effect of Oxygen Content

Oxygen is an electron acceptor. Larson et al.^[25] found that oxygen was important for the complete oxidation of 2-propanol in UV/TiO₂ system. The conversion of acetone increased from 20% to 70% at illuminating 6 min with increasing the oxygen content from 0% to 5%(v/v). Figure 4 presents that k_{app} increased with increasing the oxygen content from 0% to 20% when temperature was 138°C, water vapor was 18.7 μM, and acetone was 11.4 μM. When O₂ concentration was almost 0%, the photocatalytic oxidation of acetone could take place but k_{app} was small. The k_{app} was raised slowly when the oxygen content was higher than 10%. El-Maazawi et al.^[27] proposed TiO₂ lattice oxygen contributed to the photocatalytic oxidation in the absence of O₂. The probability for recombination of electron/hole pairs could be reduced because gas phase oxygen adsorbed on the surface to react with electrons forming super-oxide ions (O₂⁻; Eq. (3), (4)).^[28] Additionally, super-oxide ions are highly reactive species that can oxidize acetone. The adsorbed O₂ on the TiO₂ surface increases with increasing gas phase oxygen. Consequently, increasing O₂ content can promote the photocatalytic oxidation of acetone. However, the surface site was saturated with adsorbed O₂ when O₂ content was high. Increasing gas phase oxygen did not increase the amount of adsorbed O₂. Since increasing O₂ content cannot accelerate the oxidation of acetone as much as low O₂ content.



Effect of Water Vapor

Actually, the treatment of gaseous acetone is likely to be performed in the presence of water vapor. Influence of water vapor on the photooxidation is complex

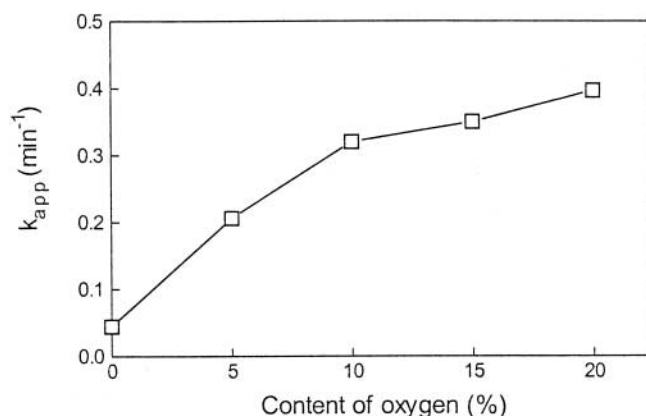


Figure 4. The variation of initial reaction-rate constant under different oxygen content (Experimental condition: temperature = 138°C; water vapor = 18.7 μM; acetone conc. = 11.4 μM).

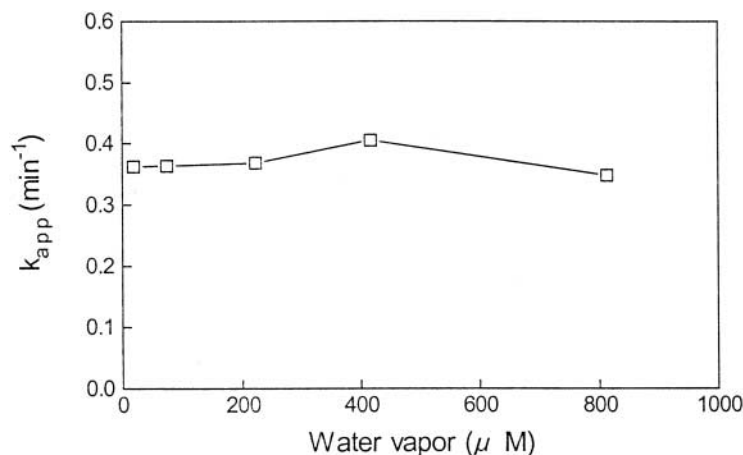


Figure 5. The variation of initial reaction-rate constant under different water vapor (Experimental condition: temperature = 138°C; oxygen = 20%; acetone conc. = 11.4 μM).

since water plays an important role in the formation of the active species (OH, Eq. (5)). In order to examine the effect of water vapor, different amount of water vapor were applied to a fixed concentration of acetone. Figure 5 shows the k_{app} vs. initial water vapor concentration varying from 18.7 to 813 μM . The photocatalytic degradation rate was enhanced by water vapor with concentrations up to 417 μM , and inhibited above 417 μM . Acetone reacting with surface hydroxyl radicals during the oxidation process caused the depletion of these hydroxyl radicals. The presence of water vapor made the catalyst surface for rehydroxylation, increasing catalytic activity.^[18] The oxidation rate of acetone was raised because the production of hydroxyl radical increased with increasing water vapor. Additionally, water vapor competed with acetone for adsorptive sites on catalyst surface.^[23] At high water vapor is beneficial to adsorption of water. Therefore, the oxidation rate of acetone was decrease at high water vapor.



Effect of Temperature

Vorontsov et al.^[8] observed temperature deactivation of TiO_2 for acetone oxidation in the flow-circulating reactor. Oxidation was quick as temperature increased to 100°C, but was slow down at higher temperature. Zorn et al.^[18] reported that the reaction rate constant of acetone significantly increased with increasing the reaction temperature from 30 to 77°C. The temperature affects strongly the photocatalytic oxidation of acetone. Therefore, experiments involving the influence of temperature in the range from 50 to 200°C were conducted. Figure 6 shows the k_{app} of acetone oxidation increasing from 50 to 100°C. Above 100°C, the k_{app} decreased with increasing temperature. In addition, the mineralization of acetone decreased at

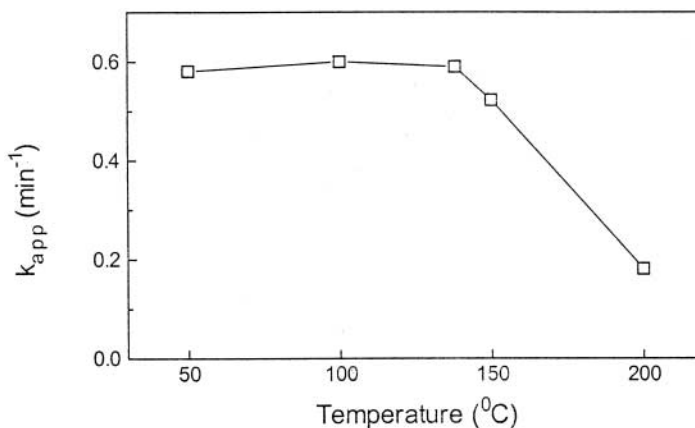


Figure 6. The variation of initial reaction-rate constant under different temperatures (Experimental condition: water vapor = 18.7 μM ; oxygen = 20%; acetone conc. = 11.4 μM).

high temperature. If one mole of acetone is completely oxidized, three moles of CO_2 are produced (Eq. (6)). In this study, the production of CO_2 is 2.5 mol per mole decayed acetone at 50°C, and one mole per mole decayed acetone at 200°C. Desorption of the products from the catalyst surface is the rate limiting step at low temperature, raising the temperature accelerates the rate of desorption.^[29] It caused k_{app} increasing from 50 to 100°C. Adsorption of the reactants was the rate limiting step at high temperature.^[30] Raising the temperature reduced the rate of adsorption. In addition, the catalyst was deactivated at high temperature.^[26] Hence the k_{app} decreased if temperature was higher than 100°C.



Kinetics

Peral and Ollis^[10] indicated the initial rate of reaction could be described by the Langmuir–Hinshelwood kinetic rate mechanism. On the assumption of no competition with reaction by-products, the simplest representation for the rates of the disappearance of acetone is given

$$r = -\frac{dC}{dt} = \frac{k_r KC}{1 + KC} \quad (7)$$

where k_r is the specific reaction rate constant, and K is the equilibrium adsorption constant.

A standard means of using this equation is to demonstrate linearity of the data when it is plotted as the inverse initial rate vs. initial concentration (Eq. (8)). As shown in Fig. 7, the plot of the reciprocal initial rate as a function of the reciprocal initial concentration yields a straight line. The linear transform of this



Oxidation of Acetone

1139

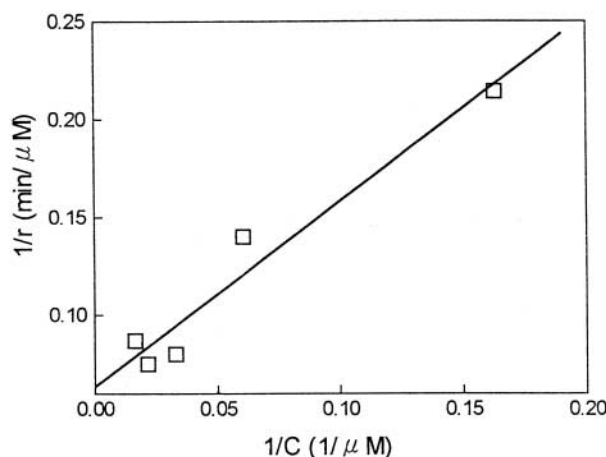


Figure 7. Linearized reciprocal kinetic plot for the photocatalytic degradation of acetone.

expression yields $k_r = 15.8 \mu\text{M}/\text{min}$ and $K = 0.0671 \text{ L}/\mu\text{M}$ ($r = 0.978$).

$$\frac{1}{r} = \frac{1}{k_r} + \frac{1}{k_r K} \times \frac{1}{C} \quad (8)$$

The integrated form of Eq. (7) is

$$t = \frac{1}{k_r K} \ln \frac{C}{C_0} + \frac{1}{k_r} (C_0 - C) \quad (9)$$

where C_0 is the initial concentration of acetone, and t is the reaction time. When $C/C_0 = 0.5$, $t_{1/2}^*$, the half-life that does not consider the competence of intermediates, can be obtained:

$$t_{1/2}^* = \frac{\ln 2}{k_r K} + \frac{0.5C_0}{k_r} \quad (10)$$

By substituting k_r and K into Eq. (10), the estimated half-lives are listed in Table 1. Figure 8 indicated the dependence of $t_{1/2}$ and $t_{1/2}^*$ on initial concentration of acetone. Clearly, the difference between $t_{1/2}$ and $t_{1/2}^*$ become larger with increasing initial acetone concentration. It was suggested that the reaction by-products competed with acetone so that delay the half-life. Figure 9 can assist the hypothesis. The degraded acetone almost turned into CO_2 at low initial concentration. Only a half of degraded acetone became to CO_2 at high initial concentration. Table 1 showed the ratios of CO_2 production to acetone degradation; they were 2.8 and 1.5 at $6.15 \mu\text{M}$ and $60.3 \mu\text{M}$, respectively. Thus, the effect of by-product on the reaction rate should be considered.

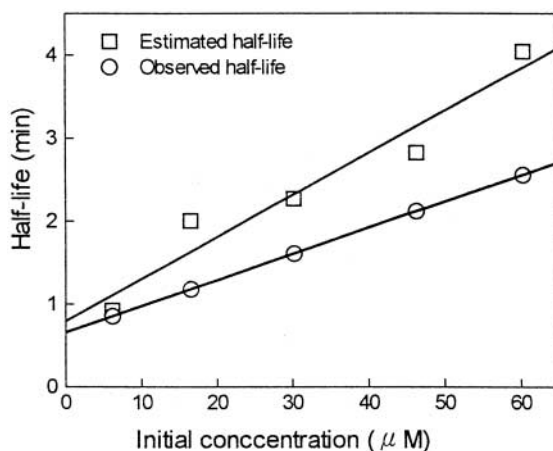


Figure 8. Dependence of observed and estimated half-lives on initial concentration of acetone (Experimental condition: temperature = 138°C; oxygen = 20%; water vapor = 18.7 μM).

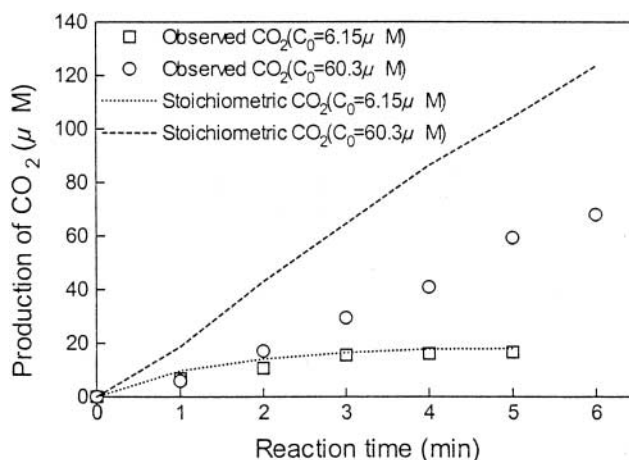


Figure 9. The production of CO₂ in photocatalytic degradation of acetone (Experimental condition: temperature = 138°C; oxygen = 20%; water vapor = 18.7 μM).

In such a case, Eq. (7) may be modified to give the equation,

$$r = \frac{-dC}{dt} = \frac{k_r KC}{1 + KC + \sum_{i=1}^n K_i I_i} \quad (11)$$

where K_i is the equilibrium adsorption constants of the i reaction product, and I_i is the concentration of the i reaction product. Integration of Eq. (11) yields:

$$t = \frac{1 + \sum_{i=1}^n K_i I_i}{k_r K} \left[\ln \frac{C_0}{C} + \frac{K(C_0 - C)}{1 + \sum_{i=1}^n K_i I_i} \right] \quad (12)$$

**Oxidation of Acetone****1141**

when $C = 0.5 C_0$, $t'_{1/2}$ gives

$$t'_{1/2} = \frac{0.5C_0}{k_r} + \frac{\ln 2}{k_r K} + \frac{\ln 2 \sum_{i=1}^n K_i I_i}{k_r K} \quad (13)$$

$t'_{1/2}$ is the half-life that considered the competence of intermediates.

Theoretically, the quantity of $t'_{1/2}$ modified with the effect of competition should approximate to those of $t_{1/2}$ observed in the reactions. Comparing Eq. (10) and Eq. (13), the different, $(\ln 2 \sum_{i=1}^n K_i I_i)/k_r K$, between $t'_{1/2}$ and $t_{1/2}$ is found. By assuming that the rate of by-product formation is directly proportional to the initial concentration, it can be realized that there showed no evidence of significant difference between $t'_{1/2}$ and $t_{1/2}$ at lower initial concentration and a consequence of obvious variation at high initial concentration. Xu and Raftery^[22] showed that the surface intermediates of photocatalytic oxidation of acetone included diacetone alcohol, mesityl oxide, formic acid, propylene oxide, and acetic acid. The half-life of acetone was extended by these intermediates competing with acetone for the oxidation. The extension time of these intermediates was shown at $(\ln 2 \sum_{i=1}^n K_i I_i)/k_r K$.

CONCLUSION

When the initial concentration is higher, the rate of degradation becomes fast. The photocatalytic decomposition reaction follows a first-order expression up to an initial acetone concentration. This is evidence of the straight line relationship between $-\ln(C/C_0)$ vs. irradiation time, and the slope is the apparent constant. The oxidation rate of acetone increased with increasing oxygen content from 0 to 20%. The photocatalytic oxidation of acetone can take place without the presence of gas-phase molecular oxygen. The water vapor enhanced the degradation of acetone at low and middle humidity but inhibits it at high water content. The apparent rate constant and mineralization of acetone decreased when temperature was higher than 138°C. Langmuir–Hinshelwood type behavior can be used to describe the photodegradation reaction; the reaction rate constant and adsorption constant are 15.8 $\mu\text{M}/\text{min}$ and 0.0671 L/ μM , respectively.

ACKNOWLEDGMENT

This work has been supported by National Science Council, Republic of China (Grant NSC 90-2211-E009-022).

REFERENCES

1. Shang, J.; Du, Y.; Xu, Z. Photocatalytic oxidation of heptane in the gas-phase over TiO_2 . *Chemosphere* **2002**, *46*, 93–99.
2. Obee, T.N.; Hay, S.O. Effects of moisture and temperature on the photooxidation of ethylene on titania. *ES & T* **1997**, *31*, 2034–2038.



3. Sun, R.-D.; Nakajima, A.; Watanabe, I.; Watanabe, T.; Hashimoto, K. TiO₂-coated optical fiber bundles used as a photocatalytic filter for decomposition of gaseous organic compounds. *J. Photochem. Photobiol. A* **2000**, *136*, 111–116.
4. Ohko, Y.; Hashimoto, K.; Fujishima, A. Kinetics of photocatalytic reactions under extremely low-intensity UV illumination on titanium dioxide thin films. *J. Phys. Chem. A* **1997**, *101*, 8057–8062.
5. Ohko, Y.; Fujishima, A. Kinetic analysis of the photocatalytic degradation of gas-phase 2-propanol under mass transport-limited conditions with a TiO₂ film photocatalyst. *J. Phys. Chem. B* **1998**, *102*, 1724–1729.
6. Ohko, Y.; Tatsuma, T.; Fujishima, A. Characterization of TiO₂ photocatalysis in the gas phase as a photoelectrochemical system: behavior of salt-modified systems. *J. Phys. Chem. B* **2001**, *105*, 10016–10021.
7. Lin, J.; Yu, J. C. An investigation on photocatalytic activities of mixed TiO₂-rare earth oxides for the oxidation of acetone in air. *J. Photochem. Photobiol. A* **1998**, *116*, 63–67.
8. Vorontsov, A.V.; Kurkin, E.N.; Savinov, E.N. Study of TiO₂ deactivation during gaseous acetone photocatalytic oxidation. *J. Catal.* **1999**, *186*, 318–324.
9. Choi, W.; Ko, J.Y.; Park, H.; Chung, J.S. Investigation on TiO₂-coated optical fibers for gas-phase photocatalytic oxidation of acetone. *Appl. Catal. B: Environ.* **2001**, *31*, 209–220.
10. Peral, J.; Ollis, D.F. Heterogeneous photocatalytic oxidation of gas-phase organics for air purification: acetone, 1-butanol, butyraldehyde, formaldehyde, and *m*-xylene oxidation. *J. Catal.* **1992**, *136*, 554–565.
11. Blount, M.C.; Falconer, J.L. Characterization of adsorbed species on TiO₂ after photocatalytic oxidation of toluene. *J. Catal.* **2001**, *200*, 21–33.
12. Einaga, H.; Futamura, S.; Ibusuki, T. Complete oxidation of benzene in gas phase by platinumized titania photocatalysts. *ES & T* **2001**, *35*, 1880–1884.
13. Wang, K.H.; Hsieh, Y.H.; Lin, C.H.; Chang, C.Y. The study of the photocatalytic degradation kinetics for dichloroethylene in vapor phase. *Chemosphere* **1999**, *39*, 1371–1384.
14. S'anchez, B.; Cardona, A.; Romero, M.; Avila, P.; Bahamonde, A. Influence of temperature on gas-phase photo-assisted mineralization of TCE using tubular and monolithic catalysts. *Catal. Today* **1999**, *54*, 369–377.
15. Shen, Y.S.; Ku, Y. Decomposition of gas-phase trichloroethene by the UV/TiO₂ process in the presence of ozone. *Chemosphere* **2002**, *46*, 101–107.
16. Sano, T.; Negishi, N.; Mas, D.; Takeuchi, K. Photocatalytic decomposition of N₂O on highly dispersed Ag⁺ ions on TiO₂ prepared by photodeposition. *J. Catal.* **2000**, *194*, 71–79.
17. Nevers, N.D. Control of volatile organic compounds (VOCs). In *Air Pollution Control Engineering*, 2nd Ed.; McGRAW-HILL Chemical Engineering Series; McGRAW-HILL Book Co.: Singapore, 2000; 329–330.
18. Zorn, M.E.; Tompkins, D.T.; Zelter, W.A.; Anderson, M.A. Photocatalytic oxidation of acetone vapor on TiO₂/ZrO₂ thin films. *Appl. Catal. B: Environ.* **1999**, *23*, 1–8.
19. Shah, J.J.; Singh, H.B. Distribution of volatile organic chemicals in outdoor and indoor air. *ES & T* **1988**, *22*, 1381–1388.

**Oxidation of Acetone****1143**

20. Sauer, M.L.; Ollis, D.F. Acetone oxidation in a photocatalytic monolith reactor. *J. Catal.* **1994**, *149*, 81–91.
21. Vorontsov, A.V.; Stoyanova, I.V.; Kozlov, D.V.; Simagina, V.I.; Savinov, E.N. Kinetics of the photocatalytic oxidation of gaseous acetone over platinumized titanium dioxide. *J. Catal.* **2000**, *189*, 360–369.
22. Xu, W.; Raftery, D. In situ solid-state nuclear magnetic resonance studies of acetone photocatalytic oxidation on titanium oxide surfaces. *J. Catal.* **2001**, *204*, 110–117.
23. Kim, S.B.; Hong, S.C. Kinetic study for photocatalytic degradation of volatile organic compounds in air using thin film TiO₂ photocatalyst. *Appl. Catal. B* **2002**, *35*, 305–315.
24. Alberici, R.M.; Jardim, W.F. Photocatalytic destruction of VOCs in the gas-phase using titanium dioxide. *Appl. Catal. B: Environ.* **1997**, *14*, 55–68.
25. Larson, S.A.; Widegren, J.A.; Falconer, J.L. Transient studies of 2-propanol photocatalytic oxidation on titania. *J. Catal.* **1995**, *157*, 611–625.
26. Vorontsov, A.V.; Savinov, E.N.; Barannik, G.B.; Troitsky, V.N.; Parmon, V.N. Quantitative studies on the heterogeneous gas-phase photooxidation of CO and simple VOCs by air over TiO₂. *Catal. Today* **1997**, *39*, 207–218.
27. El-Maazawi, M.; Finken, A.N.; Nair, A.B.; Grassian, V.H. Adsorption and photocatalytic oxidation of acetone on tio₂: an in situ transmission FT-IR study. *J. Catal.* **2000**, *191*, 138–146.
28. Jacoby, W.A.; Blake, D.M.; Fennell, J.A.; Boulter, J.E.; Vargo, L.M.; George, M.C.; Dolberg, S.K. Heterogeneous photocatalysis for control of volatile organic compounds in indoor air. *J. Air & Waste Manage. Assoc.* **1996**, *46*, 891–898.
29. Hager, S.; Bauer, R. Heterogeneous photocatalytic oxidation of organics for air purification by near UV irradiated titanium dioxide. *Chemosphere* **1999**, *38*, 1549–1559.
30. Herrmann, J.M. Heterogeneous photocatalysis: an emerging discipline involving multiphase systems. *Catalysis Today* **1995**, *24*, 157–164.

Received July 23, 2002



MARCEL DEKKER, INC. • 270 MADISON AVENUE • NEW YORK, NY 10016

©2003 Marcel Dekker, Inc. All rights reserved. This material may not be used or reproduced in any form without the express written permission of Marcel Dekker, Inc.