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# 载银活性炭活化过硫酸钠降解酸性橙7

王忠明<sup>1</sup>, 黄天寅<sup>1\*</sup>, 陈家斌<sup>1</sup>, 李文卫<sup>2</sup>, 张黎明<sup>1</sup>

(1. 苏州科技学院环境科学与工程学院, 苏州 215009; 2. 中国科学技术大学化学与材料科学学院, 合肥 230026)

**摘要:** 采用硝酸氧化的颗粒活性炭浸渍制备 Ag/GAC 活化剂, 利用 N<sub>2</sub> 吸附、SEM、FT-IR 及 XRD 对 Ag/GAC 进行表征, 得出 Ag 成功负载于颗粒活性炭上, 并以 Ag/GAC 在常温常压下活化过硫酸钠 (PS) 产生硫酸根自由基 (SO<sub>4</sub><sup>-</sup>·) 降解偶氮染料酸性橙 7 (AO7)。考察了 Ag 负载量、PS 浓度、Ag/GAC 投加量、初始 pH 对 AO7 降解效果的影响。结果表明, 当 Ag 负载量为 12.7 mg·g<sup>-1</sup>、n(PS):n(AO7) 为 120:1、Ag/GAC 投加量为 1.0 g·L<sup>-1</sup>, 降解 180 min 后 AO7 降解率达 95.0% 以上。初始 pH 对 Ag/GAC 活化 PS 降解 AO7 有较大影响, pH 为 5.0 时降解效果最优。通过紫外可见光谱、气相色谱-质谱 (GC/MS) 对 AO7 降解过程进行了探讨, 在降解过程中 AO7 的偶氮键和萘环结构均被破坏, 并检测出主要降解产物有邻苯二甲酸和乙酰苯。

**关键词:** 颗粒活性炭; 银; 活化剂; 过硫酸钠; 酸性橙 7

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## Degradation of Acid Orange 7 with Persulfate Activated by Silver Loaded Granular Activated Carbon

WANG Zhong-ming<sup>1</sup>, HUANG Tian-yin<sup>1\*</sup>, CHEN Jia-bin<sup>1</sup>, LI Wen-wei<sup>2</sup>, ZHANG Li-ming<sup>1</sup>

(1. School of Environmental Science and Engineering, Suzhou University of Science and Technology, Suzhou 215009, China; 2. School of Chemistry and Materials Science, University of Science and Technology of China, Hefei 230026, China)

**Abstract:** Granular activated carbon with silver loaded as activator (Ag/GAC) was prepared using impregnation method. N<sub>2</sub> adsorption, scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FT-IR) and X-ray diffraction (XRD) were adopted to characterize the Ag/GAC, showing that silver was successfully loaded on granular activated carbon. The oxidation degradation of acid orange 7 (AO7) by the Ag/GAC activated by persulfate (PS) was investigated at ambient temperature. The influences of factors such as Ag loading, PS or Ag/GAC dosages and initial pH on the degradation of AO7 were evaluated. The results demonstrated that the degradation rate of AO7 could reach more than 95.0% after 180 min when the Ag loading content, PS/AO7 molar ratio, the Ag/GAC dosage were 12.7 mg·g<sup>-1</sup>, 120:1, 1.0 g·L<sup>-1</sup>, respectively. The initial pH had significant effect on the AO7 degradation, with pH 5.0 as the optimal pH for the degradation of AO7. The possible degradation pathway was proposed for the AO7 degradation by using UV-visible spectroscopy and gas chromatography-mass spectrometry (GC/MS). The azo bond and naphthalene ring in the AO7 were destroyed during the degradation, with phthalic acid and acetophenone as the main degradation products.

**Key words:** granular activated carbon; silver; activator; persulfate; acid orange 7

偶氮染料是纺织、造纸、制革等工业常用染料,其生产废水具有种类多、色度大、难降解等特点<sup>[1,2]</sup>。通常采用的偶氮染料废水化学处理方法有电解氧化、光催化氧化、Fenton 氧化等<sup>[3]</sup>。近年来,基于硫酸根自由基 (SO<sub>4</sub><sup>-</sup>·) 的新型高级氧化技术 (AOPs) 由于对有机污染物具有降解快、氧化彻底、适用范围广等特点<sup>[4]</sup>, 逐渐被应用于降解偶氮染料废水, 其中活化产生 SO<sub>4</sub><sup>-</sup>· 是其应用的关键。热、紫外光、金属离子、活性炭和有机化合物 (酚类、醌类) 等条件都可以活化过硫酸盐产生 SO<sub>4</sub><sup>-</sup>·<sup>[5,6]</sup>, 其氧化还原电位  $E^0$  为 2.5 ~ 3.1 V, 理论上可以氧化大部分有机污染物<sup>[6]</sup>。其中金属离子 (Ag<sup>+</sup>、Co<sup>2+</sup>、Fe<sup>2+</sup> 等) 对过硫酸盐具有较好活化效果<sup>[7~10]</sup>, 但也存在金属离子流失和难以回收利用等局限性, 通常将金属离

子负载于载体上以解决此类问题<sup>[11~13]</sup>。颗粒活性炭具有良好的孔隙结构和吸附性能, 且具有重复利用性, 可视为理想的载体物质。因此, 本研究通过浸渍法制备颗粒活性炭负载银的活化剂, 并对活化剂进行表征, 同时考察其活化过硫酸钠降解偶氮染料 AO7 效果, 并对其降解途径及产物进行探讨。

### 1 材料与实验方法

#### 1.1 材料与试剂

颗粒活性炭购于天津大茂化学试剂厂, 研磨筛

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作者简介: 王忠明 (1991 ~), 男, 硕士研究生, 主要研究方向为污水处理与回用技术, E-mail: wangzmchn@163.com

\* 通讯联系人, E-mail: huangtianyini111@sohu.com

选 40 ~ 60 目粒径; 过硫酸钠 ( $\text{Na}_2\text{S}_2\text{O}_8$ , PS) 购于 Sigma-Aldrich; 酸性橙 7 (AO7) 购于国药集团化学试剂有限公司, 化学结构式如图 1 所示. 盐酸 ( $\text{HCl}$ )、硝酸 ( $\text{HNO}_3$ )、硝酸银 ( $\text{AgNO}_3$ )、硫酸 ( $\text{H}_2\text{SO}_4$ )、氯化钠 ( $\text{NaCl}$ )、二氯甲烷 ( $\text{CH}_2\text{Cl}_2$ )、无水硫酸钠 ( $\text{Na}_2\text{SO}_4$ ) 均为分析纯. 实验用水为去离子水.

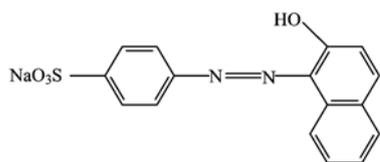


图 1 酸性橙 7 的化学结构式

Fig. 1 Molecular structure of Acid Orange 7

## 1.2 活化剂的制备与表征

活化剂制备: ①活性炭采用 5% 盐酸清洗浸泡, 以去除表面杂质, 再用去离子水洗至中性, 在  $105^\circ\text{C}$  下干燥 12 h, 置于干燥器中备用, 记为 GAC; ②称取一定量 GAC 置于 100 mL 20% 硝酸溶液中,  $70^\circ\text{C}$  恒温水浴回流 6 h 后放入超声波清洗器中超声清洗 15 min, 再反复清洗至中性, 干燥后称取适量浸渍于不同浓度  $\text{AgNO}_3$  溶液中, 避光条件下振荡 24 h 后过滤, 以佛尔哈德法 (Volhard method)<sup>[14]</sup> 滴定浸渍液前后  $\text{Ag}^+$  浓度变化, 确定理论负载量 ( $m_{\text{Ag}}/m_{\text{GAC}}$ ), 干燥后置于干燥器中备用, 记为 Ag/GAC.

活化剂表征: 活性炭负载银前后的比表面积和孔体积采用美国 Micromeritics ASAP 2020 全自动快速比表面积及介孔/微孔分析仪测定; 表面形貌采用 Phenom Pro 扫描电子显微镜 (SEM) 观察; 表面官能团利用美国 Nicolet 6700 型傅里叶变换红外光谱仪 (FT-IR) 测试; 并以德国 Bruker D8 Advance X 射线衍射仪 (XRD) 进行物相分析.

## 1.3 降解实验

向盛有 250 mL 的 AO7 溶液的具塞锥形瓶中加入一定量 PS, 再迅速加入一定量 Ag/GAC 启动反

应, 将锥形瓶置于恒温水浴振荡器 ( $20^\circ\text{C}$ ,  $160 \text{ r}\cdot\text{min}^{-1}$ ) 上振荡混匀, 在预定时间内取样, 并迅速加入一定量甲醇淬灭反应, 反应样品经  $0.45 \mu\text{m}$  滤膜过滤后测定其吸光度.

## 1.4 分析方法

染料 AO7 浓度利用 Mapada UV-1600 (PC) 紫外可见分光光度计, 在 AO7 最大吸收波长 484 nm 处测量其吸光度, 计算出对应染料浓度. AO7 矿化率采用总有机碳分析仪 (TOC-LCPH, 岛津) 测定.

降解产物采用 GC/MS 测试分析, 测试前先对反应样品预处理, 预处理过程如下: 取 30 mL 反应液, 加入几滴浓硫酸酸化 ( $\text{pH} < 2$ ), 再加入一定量氯化钠粉末, 取清液以 30 mL 的二氯甲烷萃取 3 次, 萃取液用无水硫酸钠脱水, 旋转蒸发至 1 mL, 利用 GC/MS 分析测定.

GC/MS 分析条件如下: 分析采用 Agilent 7890A/5975C 测定, 色谱柱为 HP-5 毛细管柱 ( $30 \text{ m} \times 320 \mu\text{m} \times 0.25 \mu\text{m}$ ). 质谱检测器 (MSD) 采用 EI 电离源 ( $70 \text{ eV}$ ), 离子源温度为  $230^\circ\text{C}$ . 载气 ( $\text{He}$ ) 流量为  $1.0 \text{ mL}\cdot\text{min}^{-1}$ , 进样量  $1 \mu\text{L}$ , 进样口温度为  $250^\circ\text{C}$ , 采用不分流模式. 升温程序如下:  $40^\circ\text{C}$  保持 2 min, 然后以  $12^\circ\text{C}\cdot\text{min}^{-1}$  的速率升温到  $100^\circ\text{C}$ , 再以  $5^\circ\text{C}\cdot\text{min}^{-1}$  的速率升温到  $200^\circ\text{C}$ , 最后以  $20^\circ\text{C}\cdot\text{min}^{-1}$  升温到  $270^\circ\text{C}$  保持 5 min. 降解产物的鉴定采用 Nist-11 标准图库, 匹配度大于 90%.

## 2 结果与讨论

### 2.1 活化剂的表征

#### 2.1.1 活性炭负载银前后结构参数变化

从表 1 可以看出, 经过  $\text{HNO}_3/\text{AgNO}_3$  处理后活性炭比表面积明显降低, 同时孔体积和平均孔径也略微减小. 这主要是高浓度硝酸具有强氧化性, 导致活性炭部分孔隙塌陷<sup>[15]</sup>; 活性炭负载银之后, 造成部分孔隙被堵塞, 二者共同作用使活性炭比表面积降低.

表 1 活性炭负载银前后结构参数<sup>1)</sup>

Table 1 Textural parameters of the activated carbon before and after loading silver

样品	$S_{\text{BET}}/\text{m}^2\cdot\text{g}^{-1}$	$V_{\text{total}}/\text{cm}^3\cdot\text{g}^{-1}$	$V_{\text{mic}}/\text{cm}^3\cdot\text{g}^{-1}$	$d_p/\text{nm}$
GAC	642.4	0.2747	0.1658	2.53
Ag/GAC	533.8	0.2165	0.1485	2.39

1)  $S_{\text{BET}}$  为比表面积;  $V_{\text{total}}$  为总孔体积;  $V_{\text{mic}}$  为微孔体积;  $d_p$  为平均孔径

### 2.1.2 扫描电镜分析

图 2 为 GAC 与 Ag/GAC 的表面形貌, GAC 具有

均匀规则的孔隙结构, Ag/GAC 表面分散着白色晶体的银颗粒, 颗粒平均粒径为 350 nm, 说明银相对

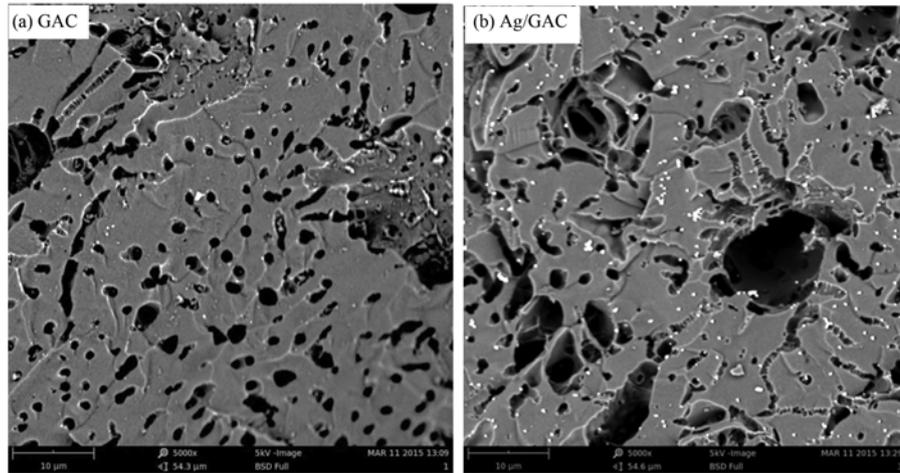


图2 GAC与Ag/GAC的SEM图

Fig. 2 SEM images of GAC and Ag/GAC

均匀的负载在活性炭上.

### 2.1.3 FT-IR 分析

活性炭负载银前后的 FT-IR 图谱如图 3 所示:  $3\ 100 \sim 3\ 400\ \text{cm}^{-1}$  处为 O—H 伸缩振动吸收峰;  $1\ 730\ \text{cm}^{-1}$  附近的吸收峰是活性炭表面羧基及内酯基中的 C=O 特征伸缩振动峰<sup>[16,17]</sup>;  $1\ 566\ \text{cm}^{-1}$  和  $1\ 383\ \text{cm}^{-1}$  处分别对应—COOH 反对称和对称伸缩振动峰<sup>[18,19]</sup>;  $1\ 170\ \text{cm}^{-1}$  处可归于  $\text{CH}_2\text{—O—CH}_2$  中的 C—O 对称伸缩振动峰<sup>[19,20]</sup>. 从图 3 中可以看出活性炭经  $\text{HNO}_3/\text{AgNO}_3$  处理后位于  $1\ 730$ 、 $1\ 566$ 、 $1\ 383\ \text{cm}^{-1}$  处振动峰明显增强, 表明羧酸和内酯类官能团含量增多. 活性炭表面含氧酸性官能团的增加, 将有利于活性炭负载银和活化过硫酸盐.

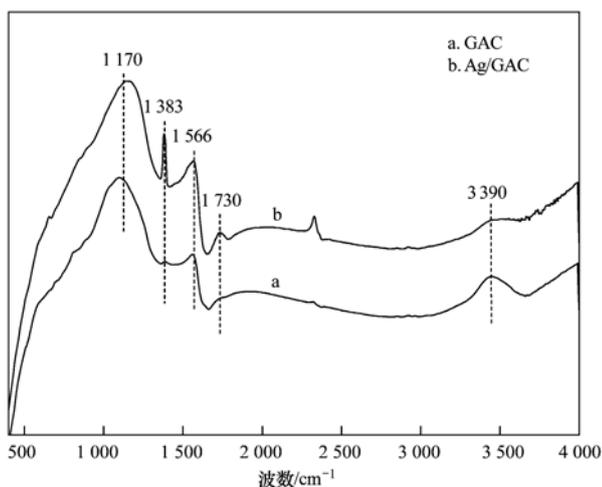


图3 GAC与Ag/GAC的FT-IR图谱

Fig. 3 FT-IR spectra of GAC and Ag/GAC

### 2.1.4 XRD 分析

目前研究认为  $\text{Ag}^+$  负载于活性炭表面是以络合

吸附-还原的方式进行. 活性炭表面—COOH、—OH 等酸性基团对  $\text{Ag}^+$  具有较强络合吸附作用, 同时  $\text{Ag}^+$  氧化还原电位  $\text{Ag}^+/\text{Ag}(0.799\ \text{V})$  较低, 易在活性炭表面发生还原[见式(1)和(2)]<sup>[21,22]</sup>.

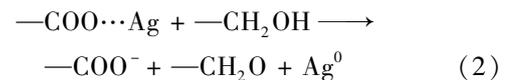
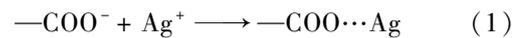


图 4 为 Ag/GAC 的 XRD 图, 由图可以看出在  $2\theta$  为  $38.17^\circ$ 、 $44.21^\circ$ 、 $64.32^\circ$  及  $77.12^\circ$  处衍射峰, 分别对应 Ag 面心立方结构 (111)、(200)、(220) 及 (311) 晶面<sup>[23]</sup>. 因此说明  $\text{Ag}^+$  在活性炭表面发生络合吸附-还原行为, 并结晶为单质银.

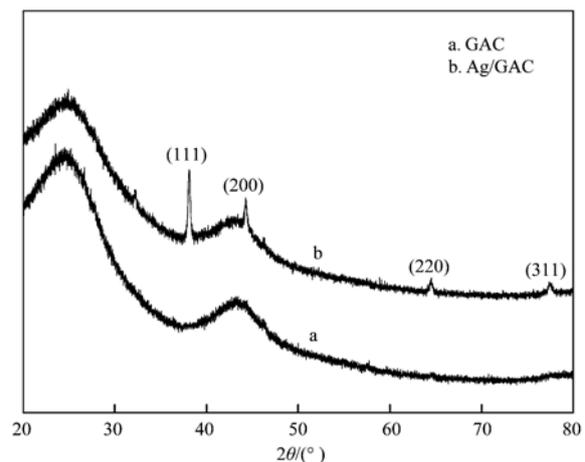


图4 GAC与Ag/GAC的XRD图

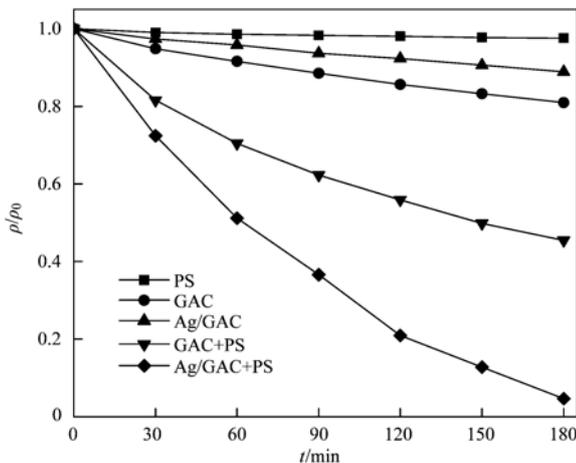
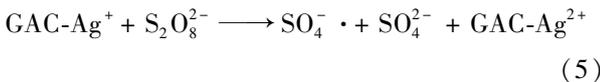
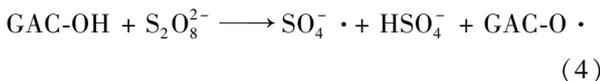
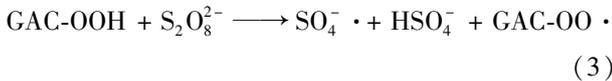
Fig. 4 XRD patterns of GAC and Ag/GAC

### 2.2 Ag/GAC 活化性能

固定 GAC 与 Ag/GAC 投加量为  $1.0\ \text{g}\cdot\text{L}^{-1}$ , 不同体系对 AO7 降解效果如图 5 所示. 在 180 min 内, PS 单独氧化 AO7 的能力较弱; Ag/GAC 相比

GAC 吸附效果下降,这与比表面积减小有关;在投加 GAC 体系中 PS 体现出较强的氧化降解能力(降解率 54.6%),证明活性炭具有活化特性;而在 Ag/GAC 的活化作用下,PS 体现出更强的氧化能力(降解率 95.3%),说明 Ag/GAC 具有良好的活化 PS 产生  $\text{SO}_4^-$  效果. 图 6 为不同体系降解 AO7 动力学分析,除 PS 单独氧化 AO7 体系,其余 4 种降解体系均符合一级降解动力学 ( $R^2 \geq 0.95$ ).

分析认为 Ag/GAC 具有良好活化效果主要有两方面因素:①活性炭表面含氧酸性官能团活化  $\text{S}_2\text{O}_8^{2-}$  产生  $\text{SO}_4^-$ ·[见式(3)和(4)]<sup>[6]</sup>;②活性炭表面络合吸附-还原的银在水中发生解离产生  $\text{Ag}^+$  与  $\text{S}_2\text{O}_8^{2-}$  反应产生  $\text{SO}_4^-$ ·[见式(5)]<sup>[7]</sup>. 两种方式活化产生具有强氧化性的  $\text{SO}_4^-$ ·,共同氧化降解溶液中的 AO7.



$\rho_0(\text{AO7}) = 20 \text{ mg} \cdot \text{L}^{-1}$ ;  $n(\text{PS}):n(\text{AO7}) = 120:1$ ; 未调节 pH

图 5 不同体系 AO7 降解效果

Fig. 5 Degradation of AO7 in different systems

### 2.3 载银量的影响

改变  $\text{AgNO}_3$  浸渍液浓度,考察活性炭不同载银量对活化降解 AO7 的影响如图 7 所示. 可以看出,随  $\text{AgNO}_3$  浸渍液浓度的提高,活性炭载银量相应增加. 原因可能是随  $\text{Ag}^+$  浓度增大,其更易与活性炭表面含氧酸性官接触,发生络合吸附-还原反应. 对于活化降解体系,随活性炭载银量的增加,AO7 降解效果越好. 当载银量为  $12.7 \text{ mg} \cdot \text{g}^{-1}$ ,降解 180

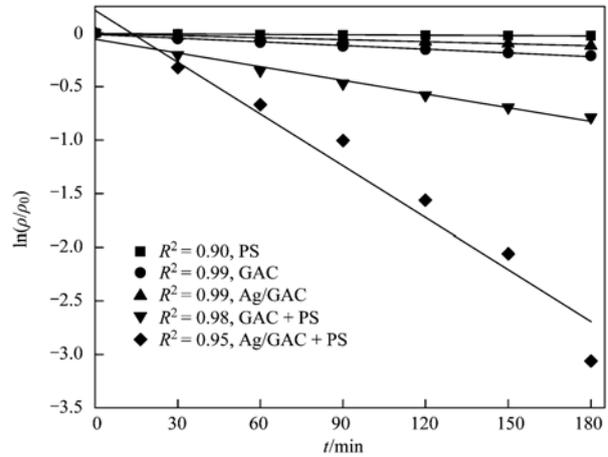
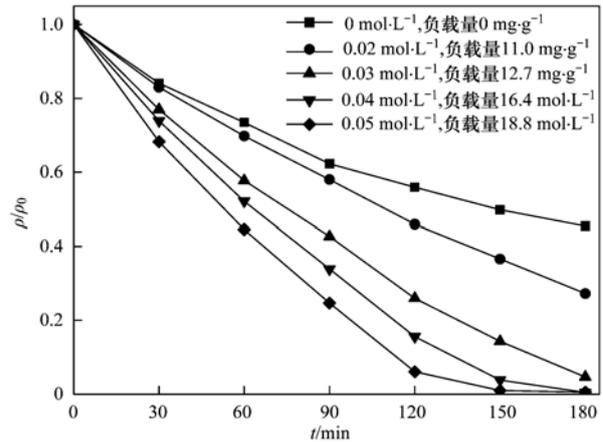


图 6 不同体系 AO7 降解动力学分析

Fig. 6 Kinetics of AO7 degradation in different system

min 时效果明显优于普通 GAC 活化效果. 因此实验选用载银量为  $12.7 \text{ mg} \cdot \text{g}^{-1}$  的活性炭作为活化剂.



$\rho_0(\text{AO7}) = 20 \text{ mg} \cdot \text{L}^{-1}$ ;  $n(\text{PS}):n(\text{AO7}) = 120:1$ ;

$\text{Ag/GAC} = 1.0 \text{ g} \cdot \text{L}^{-1}$ ; 未调节 pH

图 7 载银量对 AO7 降解的影响

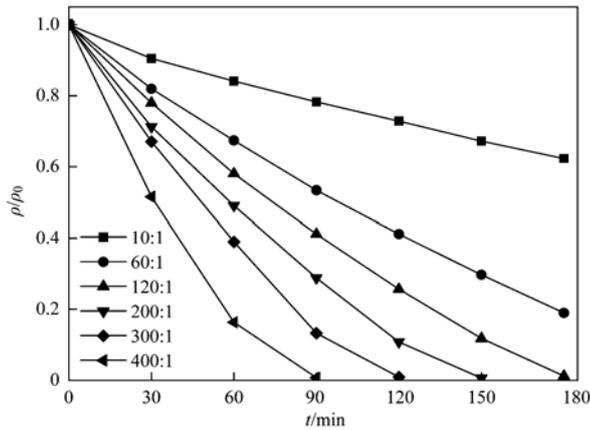
Fig. 7 Effect of Ag loading on the degradation of AO7

### 2.4 PS 浓度的影响

不同 PS 浓度对降解 AO7 的影响如图 8 所示. 当  $n(\text{PS}):n(\text{AO7})$  由 10:1 增加为 60:1 时,AO7 降解速度显著加快;当  $n(\text{PS}):n(\text{AO7})$  为 200:1、300:1、400:1 时,AO7 降解率分别在 150、120、90 min 时达到 99.0% 以上. 由此得出,随着  $n(\text{PS}):n(\text{AO7})$  初始摩尔比增大,活化降解 AO7 速率越快,降解完全所需时间越短. 有研究认为,当 PS 浓度过高时,会产生大量自由基相互湮灭,使降解速率减缓<sup>[6]</sup>. 因此 PS 浓度应控制在适当范围,后续实验选取  $n(\text{PS}):n(\text{AO7})$  为 120:1.

### 2.5 Ag/GAC 投加量的影响

Ag/GAC 的投加量对降解 AO7 的效果如图 9 所

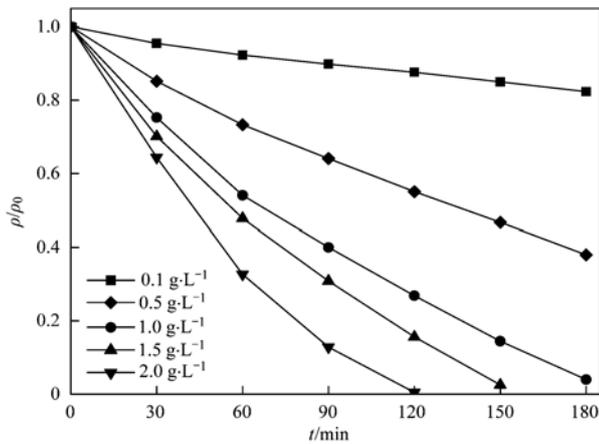


$\rho_0(\text{AO7}) = 20 \text{ mg}\cdot\text{L}^{-1}$ ;  $\text{Ag}/\text{GAC} = 1.0 \text{ g}\cdot\text{L}^{-1}$ ; 未调节 pH

图 8 PS 浓度对 AO7 降解的影响

Fig. 8 Effect of PS concentration on the degradation of AO7

示. 从中可知, 随 Ag/GAC 投加量增大, 活化降解 AO7 速率越快. 投加量为  $0.1 \text{ g}\cdot\text{L}^{-1}$  时, 180 min 时降解率仅为 17.7%, 然而投加量为  $1.0 \text{ g}\cdot\text{L}^{-1}$  时, 180 min 时降解率已达 95.0%, 继续增大投加量为  $2.0 \text{ g}\cdot\text{L}^{-1}$  时, 降解率达到 99.8% 仅需 120 min. 这主要是因为随 Ag/GAC 投加量增大, 吸附作用及活化效果增强.



$\rho_0(\text{AO7}) = 20 \text{ mg}\cdot\text{L}^{-1}$ ;  $n(\text{PS}):n(\text{AO7}) = 120:1$ ; 未调节 pH

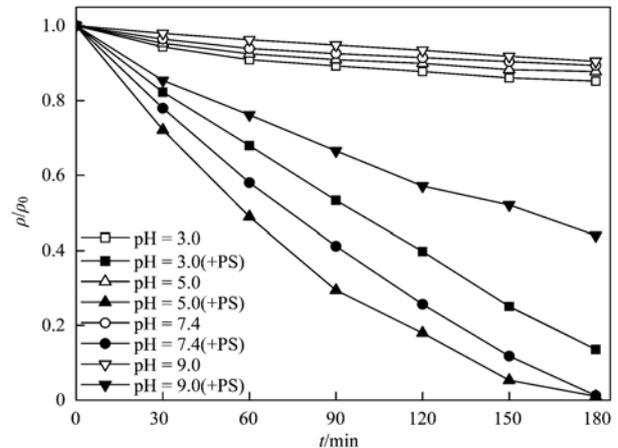
图 9 Ag/GAC 投加量的影响

Fig. 9 Effect of Ag/GAC dosage on the degradation of AO7

## 2.6 初始 pH 的影响

图 10 显示了不同初始 pH 对 Ag/GAC 活化体系降解 AO7 的影响. 从中可知, Ag/GAC 吸附效果随 pH 降低而增强, 而当  $\text{pH} = 5.0$  时, 活化体系降解效果最优. 分析认为, 这与活性炭表面电荷 ( $\text{pH}_{\text{pzc}}$ ) 有关, 当溶液  $\text{pH} < \text{pH}_{\text{pzc}}$  时, 活性炭表面带正电荷, 有利于阴离子染料吸附, 当溶液  $\text{pH} > \text{pH}_{\text{pzc}}$  时, 活性炭表面带负电荷, 有利于阳离子染料吸附<sup>[24,25]</sup>;

AO7 属于阴离子偶氮染料, pH 降低有利于 Ag/GAC 吸附. 对活化体系而言, 当  $\text{pH} = 3.0$  时 Ag/GAC 吸附较多目标物, 不利于 PS 与 Ag/GAC 表面接触, 降低了  $\text{SO}_4^{\cdot-}$  的产生; 而在碱性条件下  $\text{SO}_4^{\cdot-}$  易转化为  $\cdot\text{OH}$  [见式(6)]<sup>[26]</sup>, 同时  $\cdot\text{OH}$  会与  $\text{OH}^-$  反应使氧化剂淬灭 [见式(7)]<sup>[27]</sup>, 并且解离的  $\text{Ag}^+$  在有  $\text{OH}^-$  存在的条件下会产生沉淀, 导致活化 PS 效果减弱. 因此初始 pH 对活化反应有较大影响, 在弱酸性条件下有利于活化降解 AO7.



$\rho_0(\text{AO7}) = 20 \text{ mg}\cdot\text{L}^{-1}$ ;  $n(\text{PS}):n(\text{AO7}) = 120:1$ ;

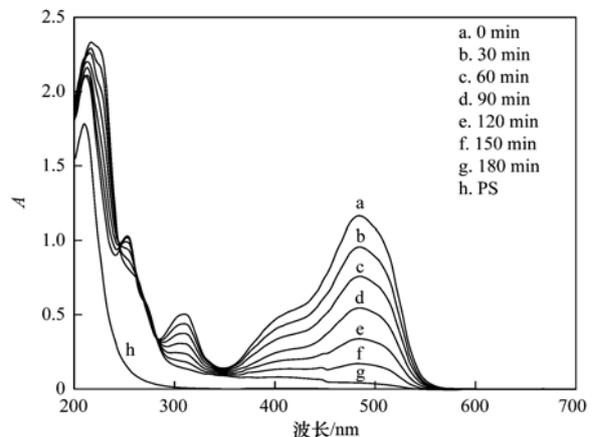
$\text{Ag}/\text{GAC} = 1.0 \text{ g}\cdot\text{L}^{-1}$

图 10 初始 pH 对 AO7 降解的影响

Fig. 10 Effect of initial pH on the degradation of AO7

## 2.7 AO7 降解紫外可见光谱及 TOC 变化

图 11 所示为 Ag/GAC 活化 PS 降解 AO7 过程中紫外可见光谱. 可以看出, AO7 主要有 484 nm



$\rho_0(\text{AO7}) = 20 \text{ mg}\cdot\text{L}^{-1}$ ;  $n(\text{PS}):n(\text{AO7}) = 120:1$ ;

$\text{Ag}/\text{GAC} = 1.0 \text{ g}\cdot\text{L}^{-1}$ ; 未调节 pH

图 11 AO7 降解紫外可见光谱

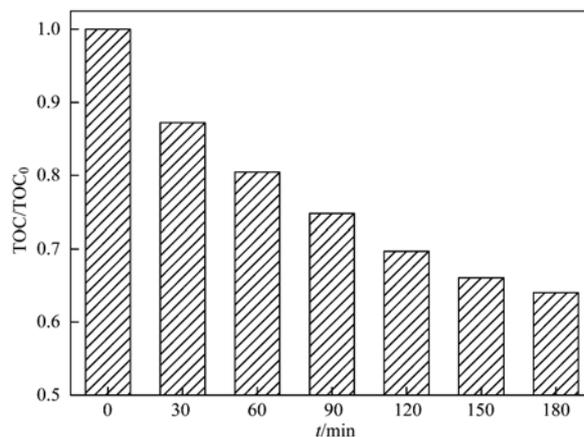
Fig. 11 UV-Vis spectra for degradation of AO7

和 310 nm 处特征吸收峰,分别代表 AO7 的发色基团偶氮键和萘环结构;同时受 PS 投加的影响,在 212 nm 处形成较强吸收峰,致使 228 nm 处代表 AO7 苯环结构的特征吸收峰<sup>[28,29]</sup>并未得到明显体现. 随活化反应进行,位于 484 nm 和 310 nm 处的 AO7 特征峰强度不断下降,表明 AO7 的偶氮键和萘环结构不断被 $\text{SO}_4^{\cdot-}$ 氧化;180 min 后偶氮键(484 nm)和萘环(310 nm)的特征峰接近消失,而在 255 nm 处形成新的吸收峰.

Ag/GAC 活化体系中 TOC 变化情况如图 12 所示,活化反应至 180 min 时,TOC 去除率达 35.9%,因此,Ag/GAC 活化体系对 AO7 不仅具有良好的降解效果而且具有一定矿化率. 同时由图 12 可以发现,反应 90 min 时体系中 TOC 下降了 25.2%,而之后 90 min 仅下降 10.7%,反应前 90 min 矿化速率较高. 原因可能是:随反应进行,生成难矿化的中间产物,同时 PS 浓度随反应进行而降低,产生的 $\text{SO}_4^{\cdot-}$ 量下降.

## 2.8 AO7 降解途径及产物分析

为进一步推测 Ag/GAC 活化 PS 降解 AO7 过程,利用 GC/MS 对 AO7 降解过程中的产物进行鉴



$\rho_0(\text{AO7}) = 20 \text{ mg} \cdot \text{L}^{-1}$ ;  $n(\text{PS}) : n(\text{AO7}) = 120 : 1$ ;

Ag/GAC =  $1.0 \text{ g} \cdot \text{L}^{-1}$ ; 未调节 pH

图 12 Ag/GAC 活化体系 TOC 去除率

Fig. 12 TOC removal in the Ag/GAC activation systems

定. 检测到主要降解产物为邻苯二甲酸和乙酰苯,其质谱如图 13 所示,结合紫外可见光谱及文献[30~32]推测其降解过程为:AO7 首先偶氮键断裂分解为芳香族化合物,再氧化开环为有机酸,进而降解为小分子酸,最后矿化为 $\text{CO}_2$ 和 $\text{H}_2\text{O}$ ,其历程如图 14 所示.

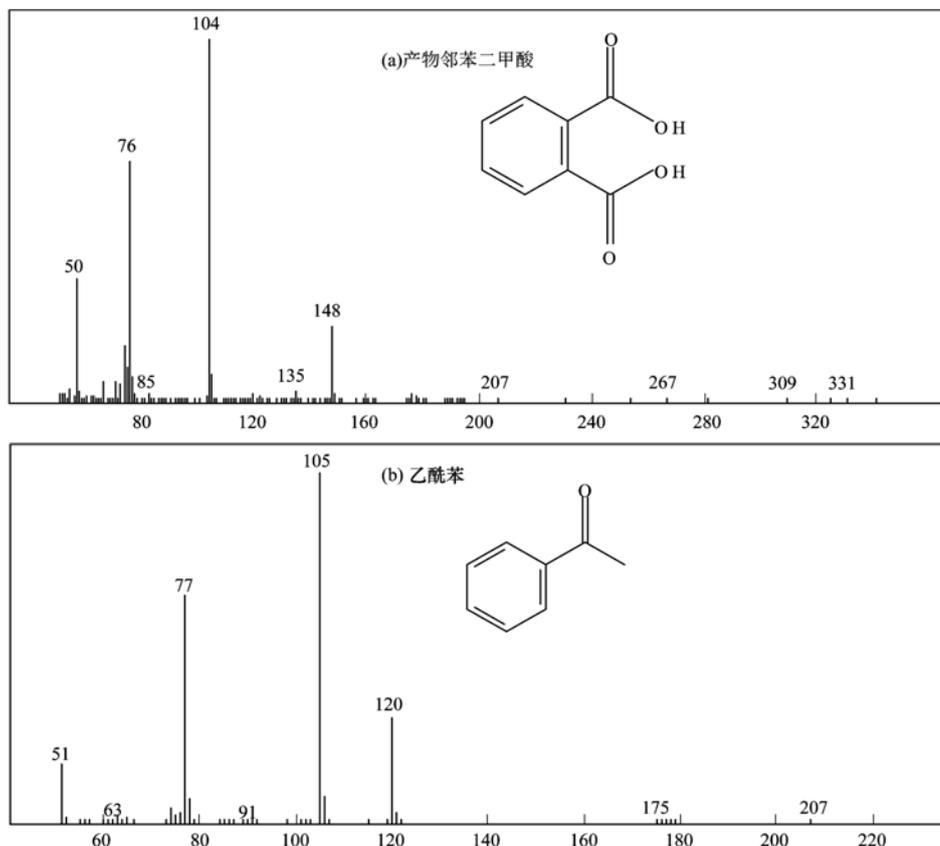


图 13 GC/MS 鉴定的 2 种主要 EI 质谱图

Fig. 13 EI mass spectra of the 2 main intermediates of AO7 degradation obtained with GC/MS

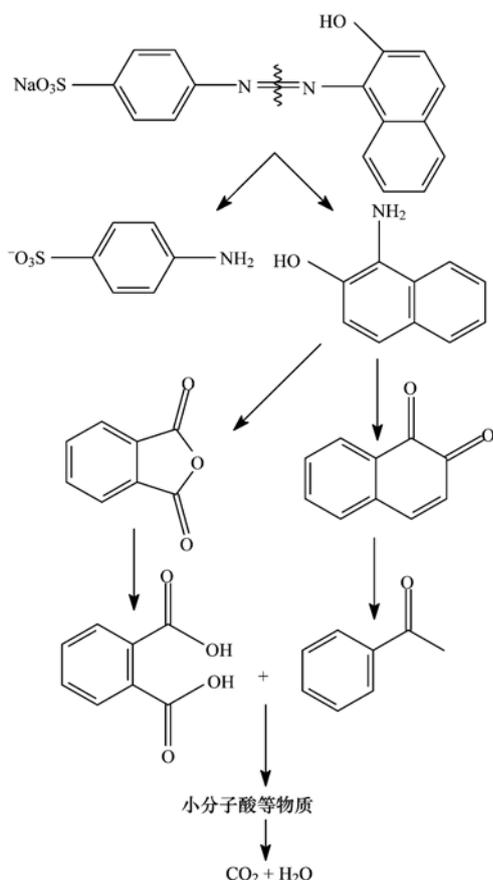


图 14 AO7 可能的降解途径

Fig. 14 A possible pathway for degradation of AO7

### 3 结论

(1) 通过浸渍法制备载银活性炭活化剂,  $\text{Ag}^+$  主要以络合吸附-还原的方式负载于活性炭表面。Ag/GAC 活化 PS 产生  $\text{SO}_4^{\cdot-}$  降解 AO7 效果良好, 并且具有一定矿化率。

(2) AO7 降解效果随 Ag 负载量、PS 浓度、活化剂投加量的增加而得到提高。初始 pH 对降解有较大影响, 在弱酸性条件有利于活化降解。

(3) GC/MS 检测出 AO7 降解产物主要有邻苯二甲酸和乙酰苯, 结合 AO7 降解紫外可见光谱结果可知, AO7 降解过程中偶氮键、萘环均一定程度被破坏, 分解为芳香族化合物, 进而矿化为  $\text{CO}_2$  和  $\text{H}_2\text{O}$ 。

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