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Oxidative Efficiency of Ozonation Coupled with Electrolysis for Treatment of Acid Wastewater

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I, Ji-Qiang Mao², Ya-Lei Ding¹, Shao-Ping T 91 (1 of 7)

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¹, Ya-Lei Ding¹, Shao-Ping Tong^{1*}
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(1.College of Chem** $\frac{1}{2}$ *Retroohem.* 2022, 28(1), 2104191 (1 of 7)

DOI: 10.13208j electrochem.210419
 Treatment of Acid Wastewater

Ze-You Hu¹, Feng-Yun Xiang², Ji-Qiang Mao², Ya-Lei Ding¹, Shao-Ping Tong¹
 Le-You Hu¹, $\begin{array}{lll} &\text{\rm \# } & \text{\# } & \text{\# } \\[1mm] \text{\textit{J.} } \textit{Electrochem. 2022, 28(1), 2104191 (1 of 7)} \end{array} \qquad \qquad \begin{array}{llll} & \text{\rm \#ttp://electrochem.xml.edu.cn}\\ & \text{\rm \#ttp://electrochem.xml.edu.cn}\\ \text{\rm \#ttp://electrochem.xml.edu.cn}\\ \text{\rm \#ttp://electrochem.xml.edu.cn}\\ \text{\rm \#ttp://electrochem.xml.edu.cn}\\ \text{\rm \#ttp://electrochem.xml.edu.cn}\\ \text{\rm \#ttp://electrochem.xml.edu.cn}\\ \text{\$

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an important and difficult task. The process of coomation coupled with electrolysis (electroly **Abstract:** Eathlishment of an exone-based advanced oxidation process (AOPs-O.) for effective treatment of acid wastevater is
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Aci Ding¹, Shao-Ping Tong^{1*}
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Treatment of Acid Wastewater

Ze-You Hu', Feng-Yun Xiang², Ji-Qiang Mao², Ya-Lei Ding', Shao-Ping Tong''

(***i.College of Chemical Engineering, State Key L* **Oxidative Efficiency of Ozonation Coupled with Electrolysis for**
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Ze-You Hu¹, Feng-Yun Xiang², Ji-Qiang Mao², Ya-Lei Ding¹, Shao-Ping Tong¹

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(***l. College of Chemical Engineering, State Key Laboratory Breding B* wastewaters. Ze-You Hu¹, Feng-Yun Xiang², Ji-Qiang Mao², Ya-Lei Ding¹, Shao-Ping Tong¹⁶
(*I. College of Chemical Engineering, State Key Laboratory Breeding Base of Green Chemistry-Synthesis
Technology, Zhejiang University of*

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his study provid 5-O₃ at pH 1.0. The results indicate that electrons can transfer
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Ozone, a strong oxidizing agent, has been

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only 48.83⁹s under the optimized conditions^[10]. Intion. The pH of the solution was adjusted with 98%

intion Fi was only 48.83% under the optimized conditions¹⁰². lution. The pH of the solution was adjusted with 98%
Some roports indicated that the combination of clear-
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bubbles through a sand distributor at the bottom of

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solutions in the study were prepared with double dis-

tilled water. The electrolyte was 5 g·L⁻¹ of Na₂SO₄ so-

lution. The pH of th All reagents used were of analytical grade, and all solutions in the study were prepared with double dis-
tilled water. The electrolyte was 5 g·L⁻¹ of Na₂SO₄ so-
lution. The pH of the solution was adjusted with 98%
 solutions in the study were prepared with double dis-
tilled water. The electrolyte was 5 g·L⁻¹ of Na₂SO₄ so-
lution. The pH of the solution was adjusted with 98%
H₂SO₄ or 40.0 g·L⁻¹ NaOH solution. The initial

Some reports indicated that the combination of elec-

H₂SO₄ or 40.0 g·L¹. NaOH solution. The initial con-

degradation efficiency of organic pollutants¹⁰¹³¹. He-

degradation efficiency of organic pollutants¹⁰ trolysis and ozonation could significantly improve the centration of HAc or acetophenone was 100 mg·L-1.

degradation efficiency of organic pollutant^{[1613}]. Election solution was 100 mg·L-1

criculation efficiency of or degradation efficiency of organic pollutants^[11,13]. Electant and a eachode could promote the mentis were performed at room temperature. Each
decomposition rate of ozone to produce hydroxyl degradation test was repeated etrolysis at an anode and a cathode could promote the

decomposition rate of cozone to produce hydroxyl degradation test was repeated three times, and the da-

decomposition rate of ozone to produce hydroxyl degradation t decomposition rate of ozone to produce hydroxyl

edgradation test was repeated three times, and the da-

radicals^{14: 51}: Therfore, E-O, has gained widespread ta in figures was the average of the triplicate results,

eon concern for its high efficiency^(16,18). Electric power is and the relative errors were all less than 59
only needed in E-O₂ process without addition of any **2.3 Analytical Methods**
study has been done to test the effi Iy needed in F-O₁ process without addition of any

c and a regular Methods

cere chemisels. However, to our best knowledge, no

determined by a high performance liquid chromatogra-

treatment of acidic wastewater so fir other chemicals. However, to our best knowledge, no

The concentrations of HAc and acetophenone were

study has been done to test the efficiency of E-O, for

determined by a high performances liquid chromategra-

the trea study has been done to test the efficiency of E-O, for

the reation of acidity existences of acidity (HPLC, Waters 1525-2996, USA), coupleyd with a

Herein, the efficiency of E-O, at pH (ses than 3 CI8 column (5 μ m, 4. the treatment of acidic wastewater so far.

Herefore, prop. (HPLC, Waters 1525-2996, USA), equipped with a

Herefore, the efficiency of E-O, at pH less than 3 C18 column (5 µm, 4.6 mm x 250 mm) and a UV

vas investigated Hercin, the efficiency of E-O₁ at pH less than 3 CI8 column (5 μ m, 4.6 mm × 250 mm) and a UV
was investigated in this work. Accide oil (HAC), and detector. The solution pHI was measured using a pH
resort in experimen han 3 C18 column (5 μ m, 4.6 mm × 250 mm) and a UV

c), an dector. The solution pH was measured using a pH

meter. The chromatographic conditions for determi-

nation of acetic acid: the mobile phase was a mixed

nation was investigated in this work. Acetic acid (HAc), an detector. The solution pH was measured using a pH

covere inter compound, was sleeted to degrade by meter. The chromatographic conditions of determi-

E-O₁^{cm, 22}. T ne inert compound, was selected to degrade by meter. The chromatographic conditions for determination and $y_1^{[3,3,3]}$. The experimental parameters of E-O₃, such and not decrete acid the mobile phase was a mixted on th to degrade by meter. The chromatographic conditions for determi-
sof E-O₂, such nation of acetic acid: the mobile phase was a mixed
efferiency of aqueous solution of 1.3131 g - L¹ phosphate buffer and
one in an acid m tilled water. The electrolyte was 5 g \cdot L⁻¹ of Na₂SO₄ so-

lution. The pH of the solution was adjusted with 98%

H₂SO₄ or 40.0 g \cdot L⁻¹ NaOH solution. The initial con-

centration of HAc or acetophenone w lution. The pH of the solution was adjusted with 98%
H₂SO₄ or 40.0 g · L⁻¹ NaOH solution. The initial con-
centration of HAc or acetophenone was 100 mg · L⁻¹.
The gas flow rate was 0.4 L · min⁻¹ and all experi-
 was adjusted with 98%

ution. The initial con-

none was 100 mg·L⁻¹.

·min⁻¹ and all experi-

phosphate times, and the da-

f the triplicate results,

less than 5%.

less than 5%.

and acetophenone were

ce liquid chr H₂SO₄ or 40.0 g \cdot L⁻¹ NaOH solution. The initial concentration of HAc or acetophenone was 100 mg \cdot L⁻¹. The gas flow rate was 0.4 L ·min⁻¹ and all experiments were performed at room temperature. Each degra centration of HAc or acetophenone was 100 mg · L⁻¹.
The gas flow rate was 0.4 L · min⁻¹ and all experi-
ments were performed at room temperature. Each
degradation test was repeated three times, and the da-
ta in figu The gas flow rate was 0.4 L •min⁻¹ and all experi-
ments were performed at room temperature. Each
degradation test was repeated three times, and the da-
ta in figures was the average of the triplicate results,
and the r ments were performed at room temperature. Each
degradation test was repeated three times, and the da-
ta in figures was the average of the triplicate results,
and the relative errors were all less than 5%.
2.3 Analytical degradation test was repeated three times, and the da-
ta in figures was the average of the triplicate results,
and the relative errors were all less than 5%.
2.3 Analytical Methods
The concentrations of HAc and acetoph ta in figures was the average of the triplicate results,
and the relative errors were all less than 5%.
2.3 **Analytical Methods**
The concentrations of HAc and acetophenone were
determined by a high performance liquid chro and the relative errors were all less than 5%.
 2.3 Analytical Methods

The concentrations of HAc and acetophenone were

determined by a high performance liquid chromatogra-

phy (HPLC, Waters 1525-2996, USA), equipped **2.3 Analytical Methods**
The concentrations of HAc and acetophenone were
determined by a high performance liquid chromatogra-
phy (HPLC, Waters 1525-2996, USA), equipped with a
C18 column (5 μ m, 4.6 mm × 250 mm) and a

 $\begin{array}{ll}\n & \text{#}\{\frac{\mu}{2}(L \text{ } \text{Electrochem.}) 2022, 28(1), 2104191 \text{ (3 of 7)}} \\
 & \text{oxygen demand (COD) was measured by the potassium dichromate method} \n\end{array}$ $\begin{array}{ll}\n & \text{a) 2022, 28(1), 2104191 \text{ (3 of 7)}} \\
 & \text{a) 2000, IDEAL, USA).} \n\end{array}$ $\begin{array}{ll}\n & \text{the concentration of O}_3 \text{ in } 0.9 \\
 & \text{the concentration of dissolved} \\
 & \text{a) 2000, IDE$.
.
. $\frac{\text{#}(E\#(J. Electronchem, 2022, 28(1), 2104191 (3 of 7))}{1.0}$

Electrochem. 2022, 28(1), 2104191 (3 of 7)

to and dichromate method^[21]. The concentration of O₃ in

gas was determined by an ozone detector (IDEAL-

2000, DEAL, U $\begin{array}{c|l|l}\n & \text{#}\{k\neq(J. \: \textit{Electrochem.}) 2022, 28(1), 2104191 \: (3 \text{ of } 7)\}\n\end{array}$ Een demand (COD) was measured by the potassi-

ichromate method^[21]. The concentration of O₂ in

ansa determined by an ozone detector (ID

oxygen demand (COD) was measured by the potentiation of O₁ in a conditional experiment diversion of dissolved

gas was determined by an extension of dissolved

centration of H_CO, was determined by an altraviolet

cent um dietoromate method²²¹. The concentration of O_x in the contribution of Cox in and those by the indige method²³. The concentration of dissolved spectrophotometer using the potassium titanium ox-
spectrophotometer u and determined by an ozone detector (IDEAL, USA). The concentration of dissolved

2000, IDEAL, USA). The concentration of dissolved¹²⁹. The concentration of H.O. was determined by an ultraviolet

spectrophotometer using 2000, DIEAL, USA). The concentration of dissolved and dissolved and the electrolysis and and $\frac{1}{2}$ and Discussion of HAC by the indig exone was measured by the indigo method^{ica}. The con-

expectrophotometer using the potassium titanum ox-

spectrophotometer using the potassium titanum ox-

spectrophotometer using the potassium titanum ox-
 3. Result contain of HA). Was determined by an ultraviolet

spectrophotometer using the potassium titanium ox-

alate method⁶²¹.
 3.2 Results and Discussion
 **3.1 The Synergistic Effect of E-O₀ Under

Acid Conditions :

Acid Example 1.1**
 Example 1.1
 Example 1.1
 Example 1.1
 Example 1.1
 Example 1.1
 Act by electrolysis, ozona
 E-O, Exaction conditions in the disputation of HAc by
 E-O, Exaction conditions: initial pH of so **Examber Schemes and DESCUSSION**
 Examber 1997
 Acid Conditions
 3.1 The Synergistic Effect of E-O₃ Under

Acid Conditions is even that the difference at the summand re-

Figure 3 effect of methanol on the degradation of HAc by

The removal rates of HAc by electrolysis, ozona

tion, **Actid Conditions**
 Action conditions

To Reachon conditions initial pH of solution: 1 at every site,

To Reachon conditions in this physical control and E-O, any min';

tion, and E-O, at pH 1 are compared, and the resu

$E-O₃$

line)

E-O₃. Reaction conditions: initial pH of solution: 1; electrolysis

$E-O₃$

0.5
 $\begin{bmatrix}\n\bullet & -\to 0_3 \\
\bullet & \bullet & \bullet \\
0 & 20 & 40 & 60 & 80 & 100 & 120\n\end{bmatrix}$
 gure 3 Effect of methanol on the degradation of HAc by
 c), Reaction conditions: initial pH of solution: 1; electrolysis

rent: 2.0 A; amount of oz 0.4
 $\frac{1}{0}$ 20 40 60 80 100 120

Figure 3 Effect of methanol on the degradation of HAc by

E-O₃, Reaction conditions: initial pH of solution: 1; electrolysis

current: 2.0 A; amount of ozone application: 23.8 mg·min 0 20 40 60 100 120

Figure 3 Effect of methanol on the degradation of HAc by

E-O₃, Reaction conditions: initial pH of solution: 1; electrolysis

current: 2.0 A; amount of ozone application: 23.8 mg ·min¹;

initial Figure 3 Effect of methanol on the degradation of HAc by E-O₃. Reaction conditions: initial pH of solution: 1; electrolysis current: 2.0 A; amount of ozone application: 23.8 mg·min⁴; initial concentration of HAc: 100 **Figure 3** Effect of methanol on the degradation of HAc by E-O, Reaction conditions: initial pH of solution: 1; electrolysis current: 2.0 A; amount of ozone application: 23.8 mg · min⁻¹; initial concentration of HAc in E-O₃, Reaction conductions: initial pri of solution: 1; efectrolysis
current: 2.0 A; amount of ozone application: 23.8 mg · min⁻¹;
initial concentration of HAc: 100 mg·L⁻¹. (color on line)
the degradation of HAc in xarian 2.9 *i*, union of state eighedian. 2.50 mg num,
initial concentration of HAc: 100 mg·L¹. (color on line)
the degradation of HAc in E-O₃ system was almost
completely inhibited after the addition of methanol,
ind the degradation of HAc in E-O₃ system was almost
completely inhibited after the addition of methanol,
indicating that hydroxyl radicals should play an im-
portant role in this process because HAc is an ozone
inert chemi the degradation of HAc in E-O₃ system was almost
completely inhibited after the addition of methanol,
indicating that hydroxyl radicals should play an im-
portant role in this process because HAc is an ozone
inert chemi the degradation of HAc in E-O₃ system was almost
completely inhibited after the addition of methanol,
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portant role in this process because HAc is an ozone
inert chemi completely inhibited after the addition of methanol,
indicating that hydroxyl radicals should play an im-
portant role in this process because HAc is an ozone
inert chemical.
3.3 Effect of Acidity on the Efficiency of
 $E-O$ indicating that hydroxyl radicals should play an im-
portant role in this process because HAc is an ozone
inert chemical.
3.3 Effect of Acidity on the Efficiency of
E-O₃
The pH value of solution is an important fact portant role in this process because HAc is an ozone
inert chemical.
 3.3 Effect of Acidity on the Efficiency of
 E-O₃

The pH value of solution is an important factor for

degradation of pollutant in E-O₁, which inert chemical.
 3.3 Effect of Acidity on the Efficiency of
 E-O₃

The pH value of solution is an important factor for

degradation of pollutant in E-O₁, which affects not

only the existent state of a pollutant i 3.3 Effect of Acidity on the Efficiency of

E-O₃

The pH value of solution is an important factor for

degradation of pollutant in E-O₁, which affects not

only the existent state of a pollutant in the solution,

but and \cdot O₂ from reduction of O₃ **the Efficiency of**

2, which affects not

1, which affects not

utant in the solution,

d O₃. In our previous

ion in the anode and

radation of nitroben-

gated^[15]. The results

cet of E-O₃ in the an-

mmpared wi **E-O₃**
C-O₃
C-O₃
C-O₂₅
C-O₂₅
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C-O25
C-O25
C-O25
C-O25
C-O3
C-O25
C-O25
C-O3
C-O3
 E-O₃
 E-O₃
 EH value of solution is an important factor for

existent state of a pollutant in the solution,

the existent state of a pollutant in the solution,

the efficiencies of ozonation in the anode and

th The pH value of solution is an important factor for
degradation of pollutant in E-O₃, which affects not
only the existent state of a pollutant in the solution,
but also the stability of dissolved O₃. In our previous
w tance in the three pathways at neutral pH: \cdot O₂ and \cdot O₂ degradation of pollutant in E-O₃, which affects not
only the existent state of a pollutant in the solution,
but also the stability of dissolved O₃. In our previous
work, the efficiencies of ozonation in the anode and
 f pollutant in E-O₃, which affects not
ent state of a pollutant in the solution,
ability of dissolved O₃. In our previous
ciencies of ozonation in the anode and
bers for the degradation of nitroben-
1 pH were investig only the existent state of a pollutant in the solution,
but also the stability of dissolved O_3 . In our previous
work, the efficiencies of ozonation in the anode and
cathode chambers for the degradation of nitroben-
zen but also the stability of dissolved O₃. In our previous
work, the efficiencies of ozonation in the anode and
cathode chambers for the degradation of nitroben-
zene at neutral pH were investigated^[15]. The results
veri work, the efficiencies of ozonation in the anode and
cathode chambers for the degradation of nitroben-
zene at neutral pH were investigated^[15]. The results
verified that the synergistic effect of E-O₃ in the an-
ode **E-O₁** C-O₁ and Schematical scavenger to in-

Methanol was chosen as a radical scavenger to in-

degradation of political in E-O₁, which affects not

vestigate the role of hydroxyl radicals in E-O₁ because that co Methanol was chosen as a radical scavenger to in-

vestigate the role of hydroxyl radicals in E-O₃ box-

condition,

cange HAC would be generated when terr-butanol re-

but also the stability of dissolved O₂. In our p vestigate the role of hydroxyl radicals in E-O₃ boxing the caistent state of a pollutant in the solution,
cause HAc would be generated when terr-butnand re-
the stability of dissolved O₃. In our previous extint hydrox cause HAc would be generated when tert-butanol re-

acts with hydroxyl radicals. As shown in Figure 3,

and the calibric of concentration of nitroben-
 $\frac{1.0}{2.0}$
 $\frac{1}{2}$
 $\frac{1}{2}$
 $\frac{1}{2}$
 $\frac{1}{2}$
 $\frac{1}{2}$
 outanol re-

but also the stability of dissolved O₃. In our previous

Figure 3,

work, the efficiencies of ozonation in the anode and

cathode chambers for the degradation of nitroben-

zene at neutral pH were investig

E-O₃. Reaction conditions: electrolysis current: 2.0 A; amount

be inferred that the role of \cdot O₃ and \cdot O₂ should play can be produced from the faster reduction of O₃ and an important role for degradation of HAc at low pH. O₂ at the cathode as the current increases.

Eigare 4 Effect of aqueous pH on the removal rate of HAc by
 $\frac{1}{2} \times 0.4$ kerassion conditions: clearly since the column indicate that the oxidation efficiency of corons

in \sim 6. Resultion conditions: (1) Δt in E-O_p Reaction conditions: electrolysis current: 2.0 A; amount

for ozone application: 23.8 mg - min⁺; initial concentration of

for ozone application: 23.8 mg - min⁺; initial concentration of

the current range of 0 of ozone upplication: 23.8 mg ·mm⁻; mital concentration of

HAc: 100 mg-1.³: (color on line)

the current should be carefully sourced the consumption for the internet range of 0 to 1.0 A. Therefore,

the electrolysis

 $H^{+[28]}$. Nevertheless, the removal of HAc was still effec-^{+[28]}. Nevertheless, the removal of HAc was still effec-

we even at pH value of 0, indicating that \cdot OH could

e produced at an acceptable rate in E-O₃ system.
 4 Effect of Current

Current is an important parame 2. 28(1), 2104191 (4 of 7)

H^{+[28]}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curren Example 12.12.104191 (4 of 7)

H^{+[28]}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of C $H^{\dagger_{D2}}(J. \text{Electrochem.}) 2022, 28(1), 2104191 (4 of 7)$
 $H^{\dagger_{D3}}$. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that •OH could

be produced at an acceptable rate in E-O₃ system

1.0
 $\begin{array}{r} 1.0 \text{ F}^{\text{10}} \text{Neutrino} & \text{H}^{\text{10}} \text{Nevertledless, the removal of HAc was still effect-
itive even at pH value of 0, indicating that 'O11 could
be produced at an acceptable rate in E-O, system.
3.4 Effect of Current is a important parameter in E-O¹,
2.6 0.5
Figure 5(A) and Figure 5(B) display the effect of current is an important parameter in E-O¹,
2.6 0.6
Figure 4. Effect of 20 A, the effi-
etero of a good 40 60 80 100 120
from the$ 1.9

as the removal of HAe was still effect

at the contract of $\frac{1}{2}$ at the set of $\frac{1}{2}$ at the content of $\frac{1}{2}$ and $\frac{$ 19.3
 $\frac{1}{2}$ 0.8
 $\frac{1$ tive even at pH value of 0, indicating that \cdot OH could
be produced at an acceptable rate in E-O₃ system.
3.4 Effect of Current
Current is an important parameter in E-O₃ ^[6,18,27].
Figure 5(A) and Figure 5(B) of **Example the set of Carrel 1** and **3.** The effect of θ and Eigent role of Current is an important parameter in E-O₁^{(8,18,79})
 θ , θ 3.4 Effect of Current
 $\begin{bmatrix}\n\frac{3}{2} & 0.8 \\
0.5 & -\frac{1}{2} & -\$ Current is an important parameter in E-O_{(185,1421})
 0.5
 0.3 0.20 40 $\frac{4}{(100)}$
 0.3 0.20 40 $\frac{60}{(200)}$
 0.3 0.20 40 $\frac{60}{(200)}$
 0.3 0.20 40 $\frac{60}{(200)}$
 0.3 0.3 0.3 0.3 0.3 0.3 $\frac{4}{10}$ $\frac{4}{10}$ $\frac{4}{10}$ $\frac{4}{10}$ $\frac{4}{10}$ $\frac{4}{10}$ $\frac{1}{10}$ $\frac{1}{10}$ on $4 \rightarrow \pm \pm 0$
 $0.3 \rightarrow \pm 0.4$ and $0.80 \rightarrow 0.9$ and $0.80 \rightarrow 0.9$ and $0.80 \rightarrow 0.80$ and h and 3. $\frac{1}{20}$ dissolved ozone in E-O, system, respectively. As the

atm winning throre are all to $\frac{1}{20}$ and $\frac{1}{20}$ do $\frac{1}{20}$ do $\frac{1}{20}$ do $\frac{1}{20}$ do $\frac{1}{20}$ do $\frac{1}{20}$ denotes of F-O, interested, ²⁶ 0 20 4 6 6 10
 ε (mm ²⁷ current increased in the range of 0 to 2.0 A, the effi-
 Figure 4 Effect of aqueous pH on the removal rate of H-Ac by clience) of E-O₃ increased. These results

E-O₃ Reaction condit **Figure 4** Effect of such as the removal rate of HAc by instabled plane and the reduced of the reduced or the reduced or the reduced or the reduced or the reduced by the reduced or the reduced or the reduced or the reduce is amount

indicate that the oxidation efficiency of ozone is im-

proved with the increase of electrolysis current, espe-

cially in the current range of 0 to 1.0 A. Therefore,

the electrolysis current should be careful 2. 28(1), 2104191 (4 of 7)

H^{+p28}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Current ²⁸⁽¹⁾, 2104191 (4 of 7)
^{+[28]}. Nevertheless, the removal of HAc was still effec-
ve even at pH value of 0, indicating that \cdot OH could
2 produced at an acceptable rate in E-O₃ system.
4 Effect of Current
Current Current is an important parameter in $E-O₃$ ^[16,18,27]. 2. 28(1), 2104191 (4 of 7)

H^{+[28]}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curren 2. 28(1), 2104191 (4 of 7)

H^{+[28]}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curren 2. 28(1), 2104191 (4 of 7)

H^{*[28]}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curre current increased in the range of 0 to 2.0 A, the renewal of HAC was still effective even at pH value of 0, indicating that \cdot OH could be produced at an acceptable rate in E-O₃ system.
3.4 Effect of Current
Current chiency.

2. 28(1), 2104191 (4 of 7)

H^{+[28]}. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect 2. 28(1), 2104191 (4 of 7)
 $H^{*[28]}$. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curr 2. 28(1), 2104191 (4 of 7)

IT⁻¹²⁸. Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curre 2. 28(1), 2104191 (4 of 7)

H^{*[28]}, Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curre chially in the current paper and the current current and the produced to achieve a to the produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Current current is an important parameter in E-O₃^[16,18,27]. 2. 28(1), 2104191 (4 of 7)

H^{-[28]}, Nevertheless, the removal of HAc was still effec-

tive even at pH value of 0, indicating that \cdot OH could

be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Curre $H^{[28]}$. Nevertheless, the removal of HAc was still effective even at pH value of 0, indicating that \cdot OH could be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Current

Current is an important par H^{-[28]}. Nevertheless, the removal of HAc was still effec-
tive even at pH value of 0, indicating that \cdot OH could
be produced at an acceptable rate in E-O₃ system.
3.4 Effect of Current
Current is an important par tive even at pH value of 0, indicating that \cdot OH could
be produced at an acceptable rate in E-O₃ system.
3.4 Effect of Current
Current is an important parameter in E-O₃^{16,18,27}.
Figure 5(A) and Figure 5(B) displ be produced at an acceptable rate in E-O₃ system.
 3.4 Effect of Current

Current is an important parameter in E-O₃^{16,18,27}.

Figure 5(A) and Figure 5(B) display the effect of cur-

rent on the removal of HAc and 3.4 **Effect of Current**
Current is an important parameter in E-O₃^{16,18,27}.
Figure 5(A) and Figure 5(B) display the effect of cur-
rent on the removal of HAc and the concentration of
dissolved ozone in E-O₃ system, r rent is an important parameter in E-O₃^[16,18,27].

e 5(A) and Figure 5(B) display the effect of cur-

on the removal of HAc and the concentration of

lived ozone in E-O₃ system, respectively. As the

nt increased in gure 5(A) and Figure 5(B) display the effect of cur-
to on the removal of HAc and the concentration of
ssolved ozone in E-O₃ system, respectively. As the
rent increased in the range of 0 to 2.0 A, the effi-
ency of E-O rent on the removal of HAc and the concentration of
dissolved ozone in E-O₃ system, respectively. As the
current increased in the range of 0 to 2.0 A, the effi-
ciency of E-O₃ increased, but the concentration of
disso dissolved ozone in E-O₃ system, respectively. As the
current increased in the range of 0 to 2.0 A, the effi-
ciency of E-O₃ increased, but the concentration of
dissolved ozone accordingly decreased. These results
indi current increased in the range of 0 to 2.0 A, the effi-
ciency of E-O₃ increased, but the concentration of
dissolved ozone accordingly decreased. These results
indicate that the oxidation efficiency of ozone is im-
prov ciency of E-O₃ increased, but the concentration of
dissolved ozone accordingly decreased. These results
indicate that the oxidation efficiency of ozone is im-
proved with the increase of electrolysis current, espe-
cial indicate that the oxidation efficiency of ozone is im-
proved with the increase of electrolysis current, espe-
cially in the current range of 0 to 1.0 A. Therefore,
the electrolysis current should be carefully controlled
 $\frac{1.0}{2.0}$
 $\frac{1.0}{2.$. Reaction conditions: electrolysis current: 2.0 A; amount **of** $\frac{10}{3}$
 $\frac{1}{2}$
 $\frac{1}{9}$
 $\frac{1}{2}$
 $\frac{1}{9}$
 $\frac{1}{$ $+1.$
 $+1.$

and \cdot O₂,(2) the COD removal of the acet proved with the increase of electrolysis current, especially in the current range of 0 to 1.0 A. Therefore,
the electrolysis current should be carefully controlled
to achieve a cost-effective operation of E-O₂. This en-

Cess of E-Cercy Sink and Cess of Exercy and the by-products of E-O.
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 Example 2.0 Removal curves of acetophenone and (B) COD removal curves of acetophenone solution by electrolysis, exonation,

and E-O, Reacti **rigure 6** (b) tennova curves on exclusions and to COV removal curves on section and B-O, Reaction conditions: initial pH of solution: 1; electrolysis current: 2.0 A; amount of coore application: 23.8 mg·min"; initial con and rone transmit and properties of E-O, increases of E-O, increases the main contains of actophenone. It can be seen from

Eignic 6(40) that are nowed by electrolysis, accounting the some of SAS's of COD were removed by degradation of acetophenone. It can be seen from

Figure 6(R) that the amounts of 3.17%, 20.87%, and

65.43% of COD were removed by electrolysis, ozona-

tion and E-O, responsively. Acciophenone can be re-

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Figure 6(B) that the amounts of 3.17%, 20.87%, and

65.43% of COD were removed by electrolysis, ozona-

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Figure 6(51) that the amounts of 5.17%₂, 0.8/%⁷⁶%, and

for 43% of COD were removed by electrolysis, ozona-

tion and E-O₃, respectively. Acetophenone can be re-

mo

Figure 6(B) that the amounts of 3.17%, 20.87%, and

66.43% of COD wers removed by electrolysis, occurs

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emoved by single ozonation, but the COD removal is

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invided wing to the selective oxidative power of
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limited owing to the selective oxidative power of

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coses. The prencentige of COD removal by the pro-

crease of E-O, was high, indicating the by-products of

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Transvection ozone. The percentage of COD removal by the pro $+60$, oxeanistic execution and the proposition of $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ and $\frac{1}{2}$ contents of an actidic wastewater $\frac{1}{2}$ cess of E-O, was high, indicating the by-products of

accorophenone degradation could also be effectively
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accorophenone degradation could also be effectively
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3.6 **Treatment of an Acidic Wastewater** (actophenone degradation could also be effectively

removed in F-O₁.
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2.15. Reaction conditions: and the midustries, thus **3.6 Treatment of an Acidic Wastewater** rate in every contention on acuta actual scale is widely used in medicine, fuel,
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4 Conclusions

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2.0. and pH of solution: 1.15; electroly C
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Figure 7 COD removal curves of an actual acidic wastevater

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tial pH of solution: 1.15; electrolysis current: 2 A; amount of o-
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droxyl radicals (GH) could be effectively produced [11] Kishimoto N, Morita Y, Tsuno H, Oomura T, Mizutani

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电解耦合臭氧化体系处理酸性废水的氧化效能

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摘要: 建立能有效处理酸性废水的臭氧类高级氧化技术(AOPs-O₃)是一个有待解决的难点。已有报道表明,臭氧氧化与电 解结合(电解臭氧化,E-O₃)可以有效降解中性溶液中的污染物。本文研究了 E-O₃ 在酸性溶液中降解乙酸(HAc,臭氧惰性物) CAU To TRESS). Outer, 2018. Starting the endeath of the starting of Cost in the starting of 的效率,发现 E-O₃ 在 pH 小于 3 时仍具有较高的氧化效率,如在 pH 为 1.0 时处理 100 mg·L⁻¹ 乙酸溶液 2 小时后 E-O₃ 的效 率达到 52.2%,而相同条件下电解和臭氧氧化的效率分别只有 2.2%和 3.5%。尽管酸度增加会降低 E-O3 的氧化效率,但在 pH 等于 0 时其仍有相对较高的氧化效率。芳族化合物苯乙酮在 pH 等于 1.0 条件下也能被 E-O3 有效地降解并矿化。机理解 析表明,溶解臭氧或氧气可以从阴极获得电子,从而产生高活性的氧化物种,如羟基自由基。在预处理了一种实际酸性废水 中 E-O₃ 也具有较好的效率。本研究为酸性废水的有效(预)处理提供了一种新方法。

关键词: 电解;臭氧;乙酸;效率;酸性废水