Effectively degradation of trace cytostatic drug capecitabine in water using porous Ti/SnO\textsubscript{2}-Sb/Ce-PbO\textsubscript{2} as a reactive electrochemical membrane

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Abstract: The electrochemical degradation kinetics of trace cytostatic drug capecitabine (CAP) at a concentration of 10 μg/L were investigated with a porous flow-through membrane anode. Electrochemical degradation of trace CAP followed the pseudo-first-order reaction kinetics. The kinetic rate constant (k) of 0.111 min\textsuperscript{-1} was found under optimal conditions. Higher current density and Cl\textsuperscript{-} concentration benefited CAP degradation. The reactive electrochemical membrane was proved to be effective for the degradation of trace CAP in water.

1. Introduction

With the rapid grow of cancer incidences, cytostatic drugs are widely used in anticancer therapy. Their consumption is also increasing due to the increase of cancer incidence [1]. In aquatic environment, the main source of these drugs is hospital and municipal wastewaters. These chemicals are proved to have carcinogenic, mutagenic and teratogenic effects to animals and human [2]. Water self-purification and conventional wastewater treatment processes (such as hydrolysis, biodegradation and photolysis) are unable to degrade these drugs effectively [3-5].

Capecitabine (CAP) is a new anticancer drug. The published work proved that UV irradiation process could effectively degrade CAP, but the toxicity was increased [6]. In our previous work, CAP with the concentration of 5-50 mg/L was effectively degraded and detoxicated by electrochemical oxidation process using a traditional plate Ti/SnO\textsubscript{2}-Sb/Ce-PbO\textsubscript{2} anode [7]. In the process, CAP was decomposed mainly by free radicals, i.e. •OH, SO\textsubscript{4}\textsuperscript{-}, and O\textsubscript{2}\textsuperscript{-}, following the pseudo zero order rate constants. Besides, the electrochemical degradation of other anticancer drugs was also investigated using BDD, Ti/RuO\textsubscript{2} or Ti/TiO\textsubscript{2} electrodes [8-11]. However, these studies were focused on their decomposition at high concentrations over 1 mg/L. Usually, the cytostatic drugs have been detected at concentrations ranging from ng/L up to μg/L in the aquatic environment and wastewaters [12]. Therefore, there still is a need of the effective degradation of trace drugs.

Electrochemical oxidation process with general electrodes is difficult in the degradation of trace organic contaminants. The main reason is that the mass transfer rate is low, which limits the overall
degradation efficiency. Recently, reactive filter anodes were reported with higher degradation efficiency of organic contaminants [13]. In the previous works, trace naproxen (50 μg/L) and stavudine (20 μg/L) were effectively decomposed using reactive filter anodes of Ti/SnO2-Sb/Ce-PbO2 and Ti/SnO2-Sb, respectively [13]. The objective of this work is to eliminate trace CAP (10 μg/L) from aqueous solution using a porous Ti/SnO2-Sb/Ce-PbO2 filter anode. The affecting factors (such as current density, Na2SO4 and Cl− concentration) on CAP degradation were investigated.

2. Experimental Sections

2.1 Materials
Capecitabine, Na2SO4, SnCl4•5H2O and antimony chloride were purchased from J&K chemical. Pb(NO3)2 and Ce(NO3)3•6H2O were purchased from Aladdin. Porous titanium tube was supplied by Baoji Yinggao Metal Material Co., LTD. China. In the preparation of Ti/SnO2- Sb/ Ce-PbO2, the interlayer was prepared using the sol-gel method, and Ce-PbO2 was produced by electrodeposition method. The detailed preparation processes could be found in the previous work [13].

2.2 Experimental Setup and Procedures
Electrochemical degradation was performed in the electrochemical filter system as described in our previously study [13]. The solution volume was 1.0 L with Na2SO4 as supporting electrolyte. The initial CAP concentration was 10 μg/L. The circulation velocity was 840 mL/min. All experiments were carried out at 298 K.

2.3 Analyses
CAP was quantified by an UPLC-MS/MS (XEVO TQD, Waters) coupled with an ESI ion source at positive ionization mode. The mobile phase consisted of 30% 0.1% formic acid and 70% methanol at a flow rate of 0.2 mL/min. Waters Xbridge BEH C18 column (2.1 mm× 50 mm, 1.7 μm) was used to separate the compounds. CAP degradation was fitted with the pseudo- first-order kinetic model.

3. Results and Discussion

3.1 Current density
The effect of applied current density on the electrochemical decompositon of CAP is shown in Figure 1. Better CAP degradation performance was found at higher current density, which was consisted with the electrochemical oxidation of CAP using plate anode [7]. The kinetic rate constant (k) values were 0.099, 0.111, 0.141 and 0.153 min−1, when the current density was 5, 10, 15 and 20 mA/cm2, respectively. At higher current density, the enhanced CAP degradation was because of the higher production of free radicals. There could be more competing reactions at higher current density, i.e. H2 and O2 evolution reactions. Thus, we used 10 mA/cm2 as the constant current density in the following experiments.
3.2 *Na₂SO₄* concentration

Figure 1. CAP degradation efficiencies with different current densities. Experimental conditions: CAP concentration of 10 μg/L, 10 mM Na₂SO₄ and pH without adjusted.

Figure 2. CAP degradation efficiencies with different Na₂SO₄ concentrations. Experimental conditions: CAP concentration of 10 μg/L, current density of 10 mA/cm² and pH without adjusted.

Na₂SO₄ acted as the electrolyte in the solution, and the effect of its concentration on CAP degradation is shown in Figure 2. The *k* values didn’t change largely when Na₂SO₄ concentration increased from 5 to 15 mM. SO₄•⁻ was proved as an important oxidation agent in electrochemical degradation of CAP in the previous work [7]. The slight change of CAP degradation efficiency after the change of Na₂SO₄ concentration mainly due to two reasons. Firstly, SO₄•⁻ production might not be enhanced after the more addition of Na₂SO₄ in the solution. Secondly, •OH and O₂•⁻ might be the more important oxidation agents than SO₄•⁻ in the CAP degradation with reactive filter anode, which is different from that in plate anode.
3.3 Cl\textsuperscript−

Cl\textsuperscript− is widely existed in waters, and plays important roles in AOPs [14]. As shown in Figure 3, the addition of Cl\textsuperscript− showed positive effect on trace CAP degradation. CAP was almost degraded thoroughly at 4 min with 100 mg/L Cl\textsuperscript− in the solution, while was degraded at the first minute with 1000 mg/L Cl\textsuperscript−. As a •OH scavenger, Cl\textsuperscript− could be oxidized to •Cl. Its oxidation ability is lower than •OH, but it is more selective and can attack electro-rich functional groups more rapidly than •OH [15]. Thus, the addition of Cl\textsuperscript− was of benefit to CAP degradation in the electrochemical oxidation process.

![Figure 3. CAP degradation efficiencies with different Cl\textsuperscript− concentration. Experimental conditions: CAP concentration of 10 μg/L, current density of 10 mA/cm\textsuperscript{2}, 10 mM Na\textsubscript{2}SO\textsubscript{4} and pH without adjusted.](image)

4. Conclusion

In this work, Ti/SnO\textsubscript{2}-Sb/Ce-PbO\textsubscript{2} filter anode was used to decompose trace CAP in water. The filter anode was effective in the electrochemical decomposition of trace CAP. The oxidative degradation follows pseudo-first-order reaction kinetics. The k value was 0.111 min\textsuperscript{−1} at CAP concentration of 10 μg/L and current density of 10 mA/cm\textsuperscript{2}. The degradation process was favored with higher current density and Cl\textsuperscript− concentration. The reactive electrochemical membrane was effective for trace CAP degradation.

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