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Artigo

PHOTOCHEMICAL CHARACTERISTICS OF DICLOFENAC AND ITS PHOTODEGRADATION OF INCLUSION COMPLEXES WITH β-CYCLODEXTRINS

Minmin Qin and Haifeng Yang
School of Biology and Environmental Science, Shanghai Normal University, ShangHai 200234, PR China
Shengwen Chen*, Hongyong Xie and Jie Guan
School of Urban Development and Environment Engineering, Shanghai Second Polytechnic University, ShangHai 201209, PR China

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Diclofenac is one of most frequently detected compounds in the water cycle. In this work, the effect of initial concentration, liquid inclusion complexes with β-Cyclodextrins (β-CDs) on the photodegradation of diclofenac are studied. Six phototransformation products are detected by HPLC chromatograms. UV-absorption spectra of diclofenac and phototransformation products were determined. One of phototransformation products was identified. The degradation followed pseudo-first-order kinetics. Experiment shows that irradiation of diclofenac in the presence of β-CDs increase photodegradation rate and the optimal mole scale of diclofenac to β-CDs is 1:2. The reduced photohaemolytic activity of diclofenac in the presence of β-CDs may be attributed to the sequestering and stabilizing of the radical intermediates and /or photoproducts by complexation.

Keywords: diclofenac; β-cyclodextrins; photodegradation.

INTRODUCTION

Diclofenac (2-[2',6'-(dichlorophenyl) amino] phenylacetic acid, DCF), a popular non-steroidal anti-inflammatory drug, is used to treat inflammatory and painful diseases.[1] Nowadays this drug is ubiquitously present in the aquatic environment.[2] These contaminants are important because many of them are not degraded under the typical biological treatments applied in the wastewater treatment plants and represent a continuous input into the environment.[3] In the aquatic environment, in river and surface waters, diclofenac is one of the most frequently detected pharmaceuticals.[4]

Diclofenac is considerably stable under normal environmental conditions and the most probable decomposition pathway for its onsite elimination is photodecomposition.[5-8] Investigation of the photolysis of labile environmental pharmaceutical contaminants is important in environmental chemistry because it presents basic data on their fates and persistence in natural environments exposed to sunlight action.[9]

Cyclodextrins (CDs) are cyclic oligosaccharides made up of six to eight α-D-glucose units connected through glycosidic- α-1,4-bonds. They are composed of hydrophobic internal cavity and hydrophilic external surface.[10] So they have the ability to form an inclusion complex with various guest molecules of suitable polarity and dimension.[11-13] This kind of special molecular structure allows them to form host/guest inclusion complex with various guest molecules with suitable polarity and dimension,[14] which can be characterized qualitatively and quantitatively by fluorescence due to the considerable alteration of the photophysical properties.[15] It has been reported that the diclofenac forms water-soluble complex with β-CDs.[16-18]

Kitano *et al*. reported that bisphenols, such as bisphenol A, are able to form an inclusion complex with CDs and its derivatives[19] and their potential as media for controlling chemical and photochemical reactions has been extensively proven.[20] In environmental research, because of CDs are nonpoisonous and biodegradable, they have been used to promote degradation of non-biodegradable pollutants discharged into aqueous environments. Kamiya *et al*.[13] has been investigated that the inclusion effect of β-CDs on the photodegradation rate of Paraoxon and found that β-CDs had a large promoting effect.[14, 21]

In this work, the formation of an inclusion complex between diclofenac and β-CDs is studied and the enhanced photodegradation behavior of diclofenac in the presence of β-CDs is investigated under different light irradiation. Effects of initial concentration, the types of light on the photodegradation of diclofenac and reaction kinetics are also discussed.

EXPERIMENTAL

Reagents

Diclofenac sodium salt is purchased from Sichuan XiYa chemical Co. Ltd. β-CDs are purchased from Sinopharm Chemical Reagent Co. Ltd. Methanol is of HPLC grade (Sinopharm Chemical Reagent Co.). Hydrochloric acid and NaOH are used to adjust the pH values of the solutions. All other reagents are of analytic reagent grade. Deionized water is used in all experiments.

Irradiation procedures

The photocatalytic degradation of diclofenac is conducted in an XPA-7 type photochemical reactor (Xujiang Machine Factory, Nanjing, China) (Figure 1) equipped with a 100 W mercury lamp (mean wavelength 365 nm) with light intensities at quartz tube positions of 12.7 mW/cm^2 (measured using a UV-A irradiation meter, Beijing Normal University, China), a halogen lamp 100 W and a 100 W xenon lamp are also used as light sources separately. The temperatures of the reaction solutions were maintained at 25±1 ^{o}C by cooling water circulation.

Degradations are performed on 50 mL of aqueous solutions containing the different initial concentrations of diclofenac, according to preliminary test. Aliquots of 2 mL suspension are sampled using a syringe at specific time intervals and filtrated through a 0.45 μm polymer membrane filters in a syringe-end filter. The pH value of the filtrates is determined immediately after filtration.

*e-mail: swchen@eed.sspu.cn

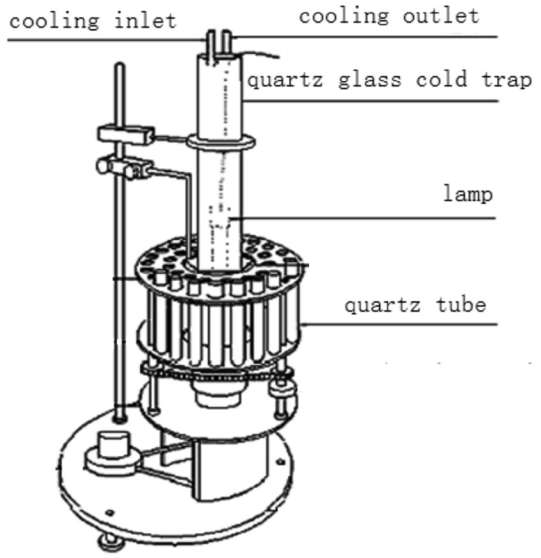

Figure 1. *Schematic diagram of photochemical reactor*

Analysis

HPLC-analysis

Diclofenac in aqueous solution is measured by HPLC (Shimadzu LC-20A pump, Shim-pack VP-DDS-C18 column (4.6 ×150 mm, 3 μm)) at a flow rate of 0.8 mL min^{-1} and a UV detector (SPD-20A detector) at 245 nm. The injection volume is 10 μL. The eluent consists of 60% methanol and 40% deionized water (pH = 2.5). Diclofenac is determined by the retention time of 12.5 min and its concentration is obtained by the peak area.

RESULTS AND DISCUSSION

Results of HPLC chromatogram analysis and photo transformations

In this study, products of photochemical reactions are identified by retention times (External reference method) in HPLC. Typical HPLC chromatograms are shown in Figure 2 under different irradiation time under a 100 W mercury lamp. It can be seen that only diclofenac at the retention time 12.5 min is detected before irradiation, and the peak height decreases with increasing irradiation time and almost disappears after 18 min irradiation. The concentration of diclofenac in the experiments is obtained from the peak area at the retention time of 12.5 min. There was a peak (peak 6) at the retention time 9.5 min and the peak value increases at first, and then decreases with increasing irradiation time, and after 18 min irradiation the peak at retention time 9.5 min disappears. Five peaks at the retention time appeared from 3 to 5 min and the peak areas increases with increasing irradiation time. As shown in Figure 2, six phototransformation products were formed during irradiation with a 100 W high pressure mercury lamp and other light sources.

The absorption spectrum of diclofenac and phototransformation in aqueous solution observed were shown in Figure 3. With comparison of the literature,[22] the UV spectrum of peak 6 was the same as that of Cz1 ((8-chloro-9H-carbazol-1-yl) acetic acid) (Figure 3S, supplementary material). The Cz1 increased at first and then decreased with increasing irradiation time too. From the above points, the peak 6 must be (8-chloro-9H-carbazol-1-yl) acetic acid. The peak 6 ((8-chloro-9H-carbazol-1-yl) acetic acid) is the primary transformation product of diclofenac under the studied conditions.

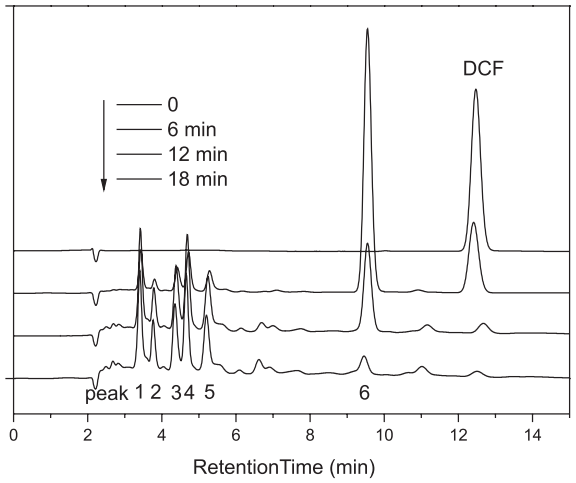

Figure 2. *HPLC chromatograms of diclofenac photodegradation under 100 W mercury lamp under different irradiation time*

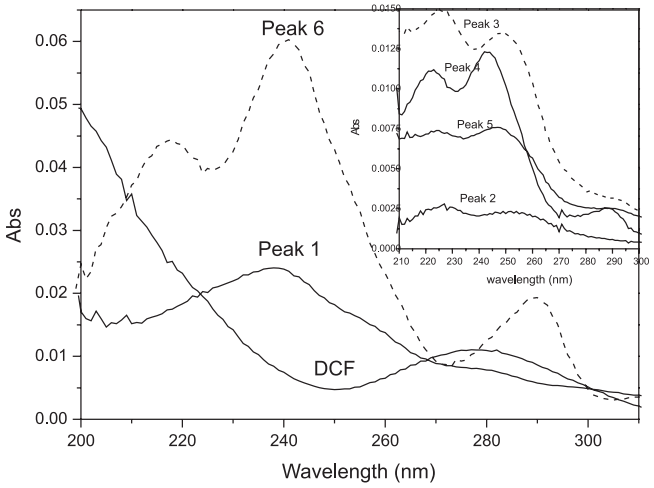

Figure 3. *Absorption spectra of diclofenac and phototransformation products*

Photodegradation kinetics of diclofenac and pH change

Experimental results indicate that the destruction rates of organic contaminants can be described by the Equation 1:

$$R = -\frac{dC}{dt} = k_{app} C_0 \quad (1)$$

The photo-inducted treatment started at neutral pH (the pH provoked by dissolving diclofenac in deionized water) but varied during the experiment from 7.35 to 4.20, shown in Figure 4, due to the dechlorination of the diclofenac molecule and the formation of carboxylic acids.

Diclofenac concentration versus irradiation time is plotted in Figure 4 at different initial concentration. In Figure 4, vertical axis is C/C_0 to illustrate overall pseudo-first-order kinetics ($\ln C_0/C = k_{app} t$) in the case of initial concentration less than 40 mg L^{-1}. The first order rate constant k_{app} is obtained from the slop of the concentration versus irradiation time curve. The initial rate ($R = k_{app} C_0$) thus can be obtained. The experiments are carried with a range of initial concentrations from 5.0, 10.0, 20.0, 40.0 mg L^{-1}. The results are shown in Figure 5. It could be seen that the initial rate of diclofenac photodegradation increases with increasing diclofenac concentration. The apparent rate constant k_{app} of diclofenac decreases from

0.43 to 0.23 min^{-1} with increasing diclofenac concentration from 5 to 40 mg L^{-1}.

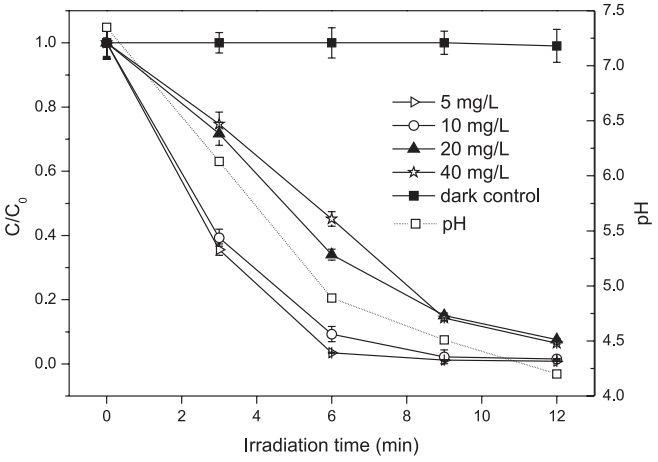

Figure 4. *C/C_0 and pH versus irradiation time*

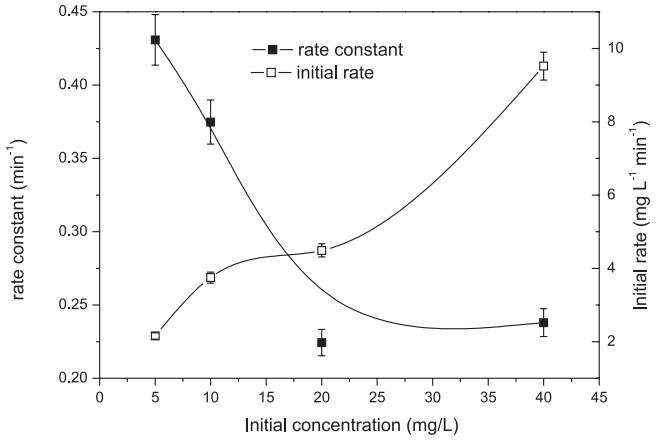

Figure 5. *The rate constant and the initial rate constant of different initial concentrations*

Photodegradation under different light sources

Experiments were performed at an initial concentration of 40 mg L^{-1} under the irradiation of four kinds light source, high pressure mercury lamp100 W, Halide Lamp 100 W, Xenon lamp 100 W and sunlight (sunny day, January, 2010; location 121.64897°E, 31.26359°N). The plot of Diclofenac concentration versus irradiation time was shown in Figure 6. Degradation of diclofenac was faster in high pressure mercury lamp than other conditions. The photodegradation reaction obeys overall pseudo-first-order kinetics under the different kinds of light sources. The rate constants k_{app} obtained from the slop of the diclofenac concentration versus irradiation time curve were listed in Table 1. From the Table 1, it can be seen that the rate of photodegradation under the different kinds of light source was in the order of Mercury lamp>Halide lamp>Xenon lamp>Sunlight.

Photodegradation of diclofenac with CDs

Diclofenac solution with or without β-CDs is irradiated under 100 W Mercury lamp light; the results are shown in Figure 7. It has been reported that ketoprofen form water-soluble complexes with β-CDs are less active than the non-complexed compounds in the photohaemolysis. Kinetic studies revealed that the presence of Hydroxypropy-β-cyclodextrin reduced drug naproxen

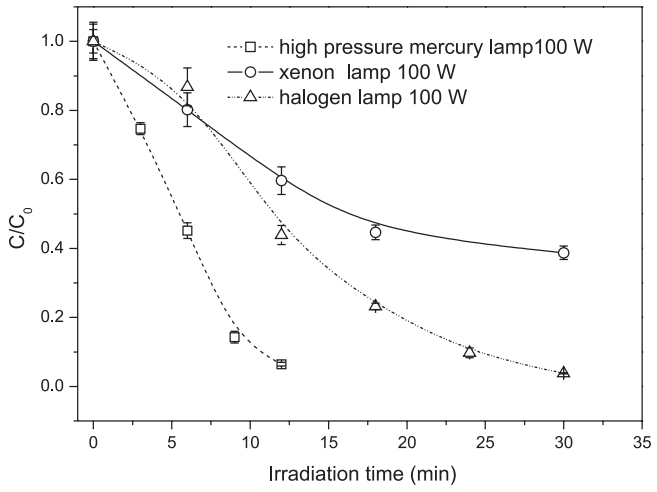

Figure 6. *C/C_0 irradiation under the different light sources of 40 mg L^{-1} of diclofenac*

Table 1. The rate constant k_{app} and initial rate R under the different light sources irradiation of 40 mg L^{-1} of diclofenac

Light sources	k_{app} (min^{-1})	R (mg L^{-1} min^{-1})	$t_{1/2}$ (min)
Sun light	0.00613	0.245	113
100 W Xenon lamp	0.0465	1.86	14.9
100 W Halogen Lamp	0.112	4.48	6.19
100 W Mercury lamp	0.238	9.51	2.91

photogradation.[23] But Figure 7 shows that formation of inclusion complexes of DCF with β-CDs was proved to increase the diclofenac photodegradation. The results are accord with naproxen with β-CDs. Jimenez reported that irradiation of naproxen in the presence of β-CDs leads to a more rapid disappearance of drug naproxen.[24] It appears that the reduced photohaemolytic activity of diclofenac in the presence of β-CDs. It can be attributed to the different behavior of the complexed radical intermediates, rather than to an increased drug photostability.

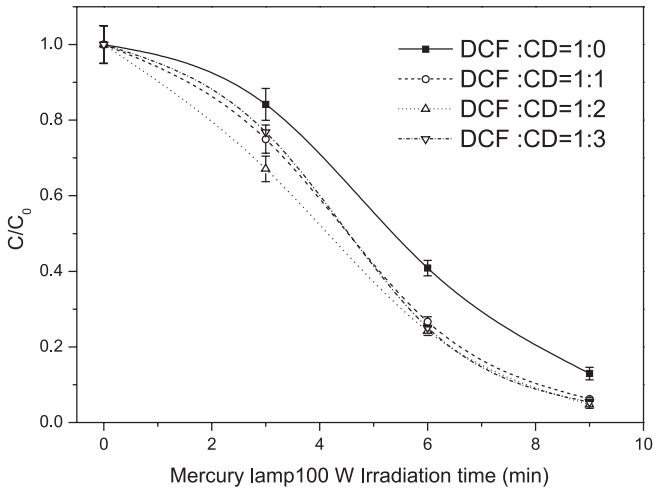

Figure 7. *Effect of mole ratio of diclofenac to β-CD under 100 W Mercury lamp*

The photodegradation reaction obeys overall pseudo-first-order kinetics. The rate constant k_{app} versus the ratio of diclofenac to β-CDs under 100 W Mercury lamps light is plotted in Figure 8. The results suggest that β-CDs induce enhancement of diclofenac

photodegradation and 1:2 is the optimum mole ratio of diclofenac to β-CDs.

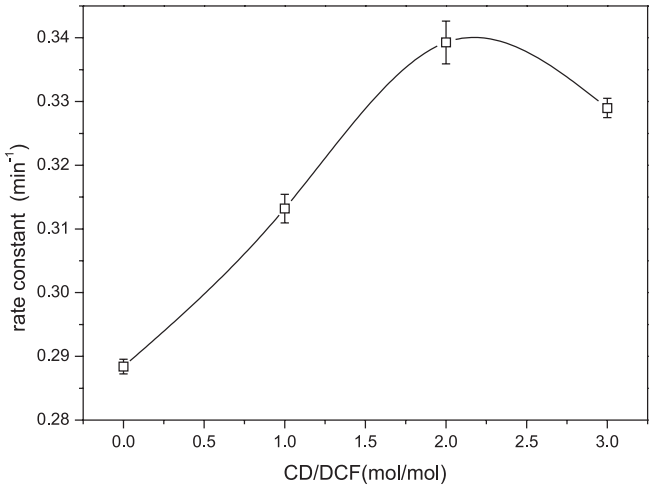

Figure 8. *The rate constant versus the mole ratio of DCF to* β*-CD*

The photodegradation of diclofenac with β-CDs under sun light irradiation are examined; the results are showed in Figure 9. It shows that the photodegradation with β-CDs has higher efficiency at longer irradiation times than that without β-CDs. The results agree with those under 100 W mercury lamps.

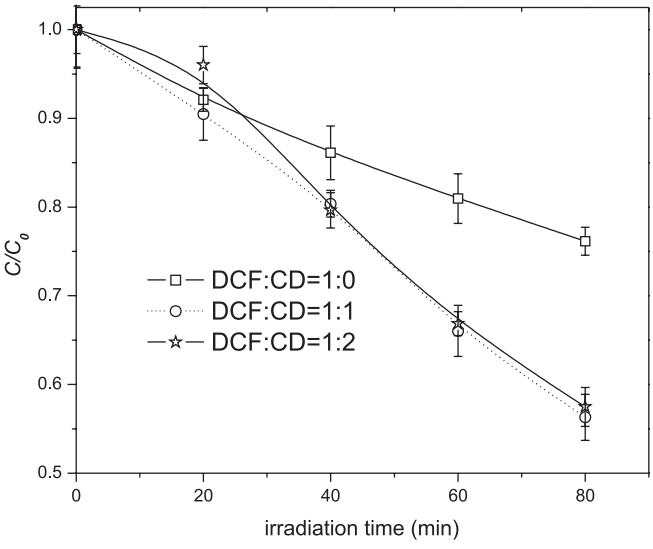

Figure 9. *Effect of mole ratio of diclofenac to* β*-CD under sun light*

CONCLUSION

In this study, photo-induced transformation of diclofenac and its liquid inclusion complexes with β-CDs has been studied in aqueous solution under different light sources. When initial DCF concentration is increased, the degradation process efficiency was low, resulting in longer half-life. The photodegradation of diclofenac follows pseudo-first-order kinetics under the different light sources. The rate constant of photodegradation under the lights is in the order of Mercury lamp> halogen lamp > Xenon lamp > Sunlight. UV-absorption spectra of diclofenac and phototransformation products were determined. One of phototransformation products was identified. Irradiation of diclofenac in the presence of β-CDs leads to a more rapid disappearance of drug diclofenac under mercury lamp or sunlight, which can be due to the behavior of complexed radical intermediates.

SUPPLEMENTARY MATERIAL

Available on http://quimicanova.sbq.org.br, in pdf file, with free access.

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