

# Degradation of *cis*-Chlordane in Aqueous Isopropanol, Isopropanol and Hexane by UV Radiation Treatment

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The degradation of *cis*-chlordane in different solvents by UV irradiation was investigated. The solvent affects the photodegradation of *cis*-chlordane where the degradation rate increases as solvent polarity increases: hexane ( $t_{1/2}$ =315 min) < isopropanol ( $t_{1/2}$ =277 min) < aqueous isopropanol ( $t_{1/2}$ =25 min). The degradation of *cis*-chlordane and the formation of a number of photoproducts were monitored and analyzed by GC-MS. Solid-phase extraction with graphitized carbon black was used to extract *cis*-chlordane and its photoproducts in aqueous isopropanol. *cis*-Chlordane degrades by dechlorination in hexane while in isopropanol and in aqueous isopropanol, it degrades by dechlorination and oxidation. The chemical structures of the photoproducts are proposed.

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**Keywords:** *cis*-chlordane; UV irradiation; photodegradation products; solid-phase extraction; GC-MS

## INTRODUCTION

*cis*-Chlordane (1,2,4,5,6,7,8,8a-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methano-1H-indene; CAS Number: 57-74-9), an organochlorine insecticide, is one of the twelve Stockholm Convention persistent organic pollutants (POPs) [1]. It is used in subsoil surface for termite control, as a termiticide to treat wood in house structures, and as an additive in plywood adhesives. The technical formulation is a mixture of many compounds, including the chlordane isomers (60-75%) and the endo-compounds heptachlor, nonachlor, diels-alder adduct of cyclopentadiene and penta-/hexa-

octachlorocyclopentadienes [1]. POPs pesticides that have been banned or restricted from use are being stockpiled in many parts of the world. Management, treatment and disposal of these stocks require, at least, a basic understanding of the degradation processes they undergo and the transformation products involved.

Among the principal pesticide degradation processes, photolysis has been used as a means of treatment for hazardous pesticides [2-6]. To degrade pesticides, various conditions and different light sources such as sunlight and xenon or mercury lamps have been used [6-9]. Aldrin,

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another POPs pesticide, for example, was degraded in water by solar photocatalysis [7]. The photocatalytic process that was monitored by mass spectrometry produced the transformation products dieldrin, chlordane, and 12-hydroxy-dieldrin. The photo-induced degradation of *cis*- and *trans*-chlordane has been studied in benzophenone, acetone and rotenone that act as sensitizers [10-13]. In sensitizing solvents, chlordane photoisomerizes to produce half-cage analogues. The identified chlordane photoisomers were 1,3,4,7,8,9,10,10-octachlorotetracyclo-[5.2.1.0<sup>2,6</sup>.0<sup>4,8</sup>]decane and 1,3,4,7,8,9,10,10-octachlorotetracyclo-[5.2.1.0<sup>2,6</sup>.0<sup>4,9</sup>]decane.

POPs pesticides have limited solubility in water. Although most degradation studies of these compounds are carried out in aqueous solutions, some photodegradation processes are performed in organic solvents or aqueous organic media. For example, the photocatalysis of the broad spectrum insecticide pyridaben was investigated in 8:2 acetonitrile-water mixture [14]. Aside from the advantage of increased solubility, acetonitrile was found to control the oxidative activity at the interface of the reaction mixture and the solid photocatalyst. Other studies that use water and aqueous organic media include the degradation of diafenthuron (an insecticide and acaricide), fluchloralin (a pre-emergence herbicide), and fenamirol (a broad-spectrum fungicide) in acetonitrile-water or methanol-water solutions [4,8,15]. The POPs incineration by-products polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) were studied to photodegrade in water and acetonitrile-water solutions [16]. The PCDDs degraded faster in acetonitrile-water solution than in pure water while for PCDFs, this solvent effect was reversed. The POPs compound hexachlorobenzene, a fungicide and an industrial chemical of varied uses, was also studied to be photodegraded in hexane and acetonitrile as well as in aqueous solution [17].

Photodegradation studies in aqueous or aqueous organic solutions generally use liquid-liquid extraction, solid-phase extraction, separation by semi-preparative HPLC using C18 columns, or vacuum concentration before gas chromatographic analysis. Solid-phase extraction with graphitized carbon black has been used in the analysis of trace

organic pollutants in environmental water samples. Graphitized carbon black is used as a reverse-phase sorbent or anion exchanger in solid-phase extraction of a wide range of compounds, in multi-residue analysis and in photodegradation studies [18-21].

This study aimed to describe the UV degradation of *cis*-chlordane in unsensitized media such as hexane, isopropanol, and aqueous isopropanol and to determine the possible transformation products in each medium. In addition, a solid-phase extraction using graphitized carbon black was explored to monitor the photodegradation of *cis*-chlordane in aqueous isopropanol that cannot be directly analyzed by GC-MS.

## EXPERIMENTAL

**Chemicals.** *cis*-Chlordane (99 %) and pentachloronitrobenzene (99.9 %) were purchased from Cambridge Isotope Laboratories, Inc. (USA) and Supelco (USA), respectively. The solvents were purchased from Wako Pure Chemical Industries, Ltd. (Japan) and Cica-Reagent Kanto Chemical, Co., Inc., (Japan): acetone, 99.8 %; ethanol, 99.5 %; isopropanol, 99.5 %; methanol, 99.8 %; hexane, 96 %.

Milli-Q water was prepared using a PF Filter Organo-Model III Apparatus and Millipore Simpli Lab UV Ultrapure System.

**UV irradiation.** *cis*-Chlordane ( $2.44 \times 10^{-5}$  M) in isopropanol (or in hexane) was irradiated in a cylindrical glass reactor (ca. 1.4 L) with an inner quartz tube encasing a 1.7 W low pressure Hg lamp (Germipak UV Cell GCL212, Light Sources, Inc., USA) that mainly emits a wavelength of 254 nm. Using a UVX radiometer (UVP, Inc., USA), the radiation flux was measured to be 6.72 mW/cm<sup>2</sup>. Triplicate samples were taken every 30 min during the first 3 h of irradiation and were directly analyzed by GC-MS. After 3 h, samples were taken every hour until after 9 to 10 h, and the last samples were taken after 19 to 24 h.

*cis*-Chlordane ( $1.22 \times 10^{-5}$  M) in 30:70 isopropanol-water was irradiated with UV light as described above and analyzed by solid-phase extraction followed by GC-MS.

**Graphitized carbon black extraction.** Irradiated samples of *cis*-chlordane in aqueous isopropanol were extracted on graphitized carbon black (Supeclean Envicarb, 250mg/3mL) using a 12-port Visiprep SPE vacuum manifold purchased from Supelco. The solid-phase was conditioned with 5 mL hexane, 5 mL 10:90 acetone-hexane, 5 mL methanol, and 5 mL 30:70 isopropanol-water in succession. A 20 mL sample was allowed to pass through the column at 3-4 mL min<sup>-1</sup> flow rate. The solid-phase was then washed with 2 mL 30:70 isopropanol-water and allowed to dry under vacuum. Elution was performed with 0.5 mL methanol, 6 mL 10:90 acetone-hexane, and 6 mL hexane. The eluate was concentrated to almost dryness using a gentle stream of nitrogen gas and reconstituted with hexane to 1 mL before analysis by GC-MS.

**GC-MS analysis.** The irradiated solutions and extracts were analyzed on an Agilent 6890N GC system equipped with a 5973 mass selective detector and an HP-5MS column (5 %-diphenyl-95 %-dimethylsiloxane) of 30 m length, 0.25 mm i.d. and 0.25 µm film thickness. The instrument was operated in the positive EI mode at 70 eV and the following conditions: injector temperature 250 °C; detector temperature 320 °C; the oven temperature was initially set at 100 °C and held for 2 min, followed by a 10°/min rise to 280 °C, and isothermally held for 2 min at the final temperature. Helium was used as carrier gas at 66.5 kPa pressure and 0.9 mL min<sup>-1</sup> flow rate. The samples (2 µL) were injected in the splitless mode.

The quantitative determination was done with standard calibration solutions ( $r^2 = 0.997-0.999$ ). Chlordane was monitored with *m/z* 373 as target ion and *m/z* 272 as confirmation ion. The internal standard pentachloronitrobenzene, which was added after extraction and before injection into the GC, was monitored with masses 237 and 295.

## RESULTS AND DISCUSSION

Because of *cis*-chlordane's low solubility in water (56 µg L<sup>-1</sup> at 25°C; log *K*<sub>ow</sub> 6.0), this UV degradation study was carried out in organic and aqueous organic solvents. For the irradiated

aqueous isopropanol solutions of *cis*-chlordane, an extraction step was required before determination by GC-MS. The SPE procedure using graphitized carbon black was based on a previous degradation study of a number of pesticides, including chlordane, that were dissolved in 30:70 ethanol-water solutions [22].

The recovery of 1.22x10<sup>-5</sup> M of the pesticides in aqueous ethanol ranged from 69 to 109 %, where the recovery of chlordane was 106 %. Aqueous ethanol, therefore, is a good solvent for studying the UV degradation of *cis*-chlordane. However, ethanol is a relatively expensive alcohol. In a study on the dechlorination of an environmental pollutant 1,1,2-trichloro-trifluoroethane (CFC113) by UV irradiation, isopropanol was found to be more effective than ethanol or methanol [23]. Isopropanol was thus used as an alternative for ethanol in the present study.

The SPE procedure was applied for the extraction of *cis*-chlordane in 30:70 isopropanol-water solutions. Increasing the isopropanol content increases the amount of *cis*-chlordane that can be dissolved in solution. But this may decrease the extraction recovery as *cis*-chlordane will preferentially remain in solution and pass through the solid phase during extraction. Decreasing the isopropanol content, on the other hand, limits the amount of *cis*-chlordane that can be dissolved in an aqueous isopropanol solution. The maximum concentration of *cis*-chlordane in a 30:70 isopropanol-water solution at ambient conditions was 2.44x10<sup>-5</sup> M. The 30:70 isopropanol-water ratio was used in the photodegradation of *cis*-chlordane in aqueous isopropanol for comparison with its degradation in pure isopropanol and in hexane. The extraction recovery of 2.44x10<sup>-5</sup> M *cis*-chlordane in 30:70 isopropanol-water using graphitized carbon black SPE was 62 % with standard deviation of 5 from four replicates.

Figure 1 shows the degradation of *cis*-chlordane in hexane, in isopropanol, and in aqueous isopropanol over time where the data is presented as percent *cis*-chlordane in solution. The photodegradation was fastest in aqueous isopropanol with almost complete disappearance of *cis*-chlordane in less than 240 min. *cis*-Chlordane was still detected after over 1200 min of UV irradiation in isopropanol and in hexane.

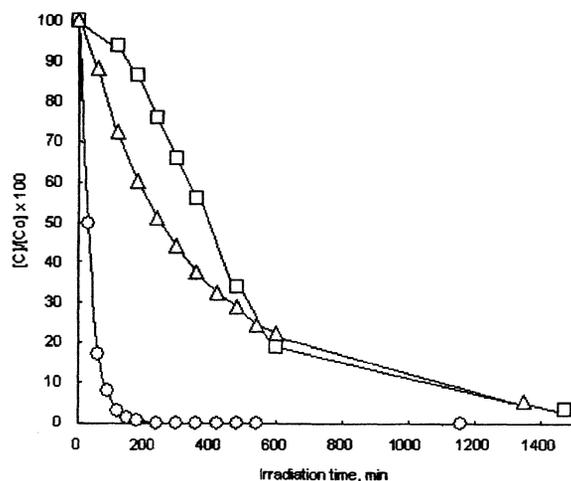


Fig. 1. Degradation of *cis*-chlordane in aqueous isopropanol (○), in isopropanol (□) and in hexane (△)

The degradation of *cis*-chlordane in the three media fits the first-order reaction model:  $\ln C_t/C_0 = -kt$  and  $t_{1/2} = \ln 2/k$ , where  $C_t$  and  $C_0$  are concentrations at a given time  $t$  and time 0, respectively,  $k$  is the reaction rate constant, and  $t_{1/2}$  is the half-life. The slopes of the linear plots  $\ln C_t/C_0$  against time evaluated the rate constants of 0.0022, 0.0025 and 0.028  $\text{min}^{-1}$  for the degradation in hexane, in isopropanol, and in aqueous isopropanol, respectively. The half-lives were calculated on data points of at least 50 % decay or total loss of *cis*-chlordane signal. The half-life values were 315, 277, and 25 min for *cis*-chlordane degradation in hexane, in isopropanol, and in aqueous isopropanol, respectively.

The rate of degradation was observed to depend on the reaction medium. Solvent polarity appeared to affect the photodegradation of *cis*-chlordane where the fastest decrease in concentration was observed in the most polar aqueous isopropanol solution, and the slowest was in the nonpolar hexane. Isopropanol and hexane have Snyder polarity indices of 4.3 and 0, respectively. The water-isopropanol medium is the most polar where the added water has a polarity index of 9.0. In the aqueous organic medium or in the relatively polar solvent such as isopropanol, the degradation or transformation of pesticides by photolysis is favorable as observed in this study and in other studies [5,15].

The transformation products from the UV irradiation of *cis*-chlordane in the three media were determined by GC-MS. At least eight transformation compounds were detected, although none of these compounds found a match in the U.S. National Institute of Standards and Technology (NIST) mass spectral library version 2.0 used in this study. Because authentic standards for these photodegradation products were not available, their molecular structures were elucidated from the mass spectra and their fragmentation patterns.

Figure 2 compares the total ion chromatograms of *cis*-chlordane solutions that were irradiated for 60 min in the three media. Figure 2 shows that more peaks are obtained in aqueous isopropanol, hence, more photodegradation products were formed in this medium. Table 1 summarizes the main degradation products and the fragmentation patterns of these photoproducts in the three media.

Under the experimental conditions, the octachloro-caged isomers ( $m/z$  406, 375, 270, 275, 100) of *cis*-chlordane previously reported in sensitized solvents were not detected in this study. The half-cage isomers that can be confirmed by the molecular ion 406 and the base peak mass 375 [12] were not detected in the UV irradiated solutions of *cis*-chlordane in hexane, in isopropanol, and in aqueous isopropanol.

The peaks at retention times 15.76 min (PP-3) and 15.84 min (PP-4) were common in the three media and were the only photodegradation products detected in the hexane solutions. Figure 3 shows the appearance of these peaks in aqueous isopropanol, isopropanol, and hexane during UV irradiation. PP-3 and PP-4 were detected in relatively higher amounts in aqueous isopropanol during the first 60 min of irradiation. They showed maximum amounts in around 600 min of irradiation time in isopropanol and in hexane. PP-3 and PP-4 showed persistence in the three media, except for PP-4 in aqueous isopropanol that was no longer detected after 1157 min of UV light exposure.

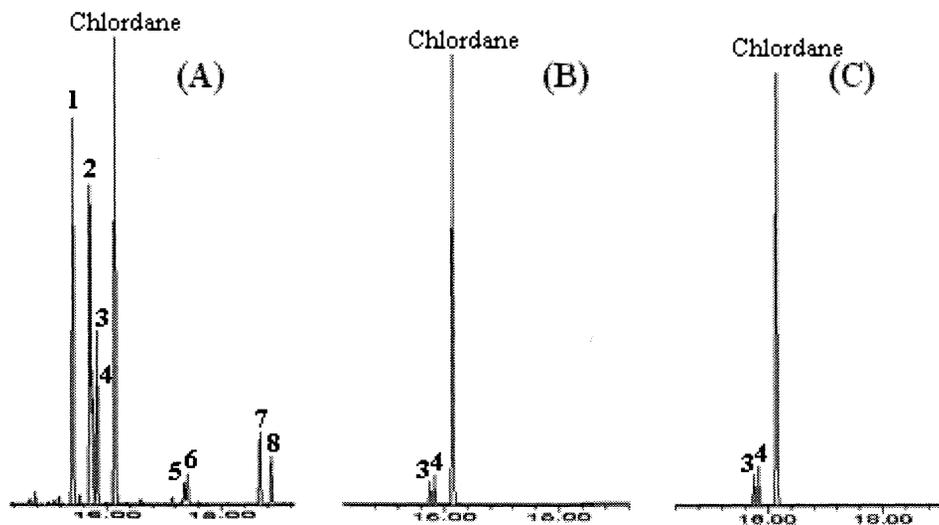
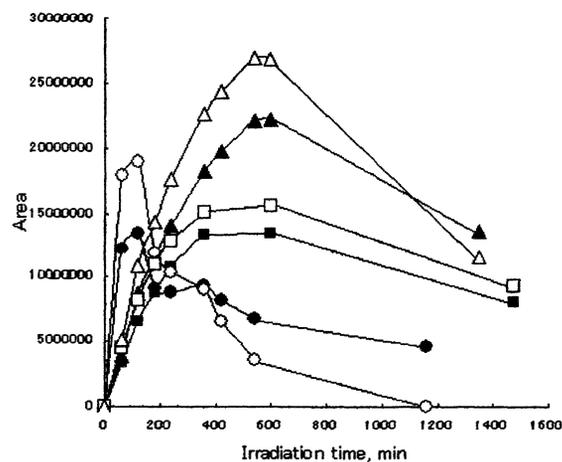


Fig. 2. Total ion chromatograms of *cis*-chlordanes in aqueous isopropanol (A), in isopropanol (B), and in hexane (C) after UV irradiation for 60 min [1: PP-1; 2: PP-2; 3: PP-3; 4: PP-4; 5: PP-5; 6: PP-6; 7: PP-7; 8: PP-8]

Table 1. Proposed photodegradation products of *cis*-chlordanes in different media

| Compound/<br>Photodegradation<br>product                                             | Retention<br>time, min | Medium                                         | Molecular ion peak, [M <sup>+</sup> ]<br>and other fragment ions <sup>a</sup>                                                                                           |
|--------------------------------------------------------------------------------------|------------------------|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>cis</i> -Chlordane<br>C <sub>10</sub> Cl <sub>8</sub> H <sub>6</sub><br>MW 409.75 | 16.16                  | Aqueous isopropanol;<br>Isopropanol;<br>Hexane | 410 [M <sup>+</sup> ]; <u>373</u> (M <sup>+</sup> -1Cl); 337 (M <sup>+</sup> -2Cl); 301 (M <sup>+</sup> -3Cl)                                                           |
| PP-1<br>C <sub>10</sub> Cl <sub>6</sub> H <sub>8</sub> O <sub>2</sub><br>MW 372.864  | 15.42                  | Aqueous isopropanol;<br>Isopropanol            | 374 [M <sup>+</sup> ]; 339 (M <sup>+</sup> -1Cl); 303 (M <sup>+</sup> -2Cl); 267 (M <sup>+</sup> -3Cl); <u>238</u> (M <sup>+</sup> -3Cl-COH); 203 (M <sup>+</sup> -5Cl) |
| PP-2<br>C <sub>10</sub> Cl <sub>6</sub> H <sub>8</sub> O <sub>2</sub><br>MW 372.864  | 15.72                  | Aqueous isopropanol;<br>Isopropanol            | 374 [M <sup>+</sup> ]; 339 (M <sup>+</sup> -1Cl); 303 (M <sup>+</sup> -2Cl); 267 (M <sup>+</sup> -3Cl); <u>238</u> (M <sup>+</sup> -3Cl-COH); 203 (M <sup>+</sup> -5Cl) |
| PP-3<br>C <sub>10</sub> Cl <sub>7</sub> H <sub>5</sub><br>MW 373.29                  | 15.76                  | Aqueous isopropanol;<br>Isopropanol;<br>Hexane | 374 [M <sup>+</sup> ]; <u>339</u> (M <sup>+</sup> -1Cl); 303 (M <sup>+</sup> -2Cl); 267 (M <sup>+</sup> -3Cl)                                                           |
| PP-4<br>C <sub>10</sub> Cl <sub>6</sub> H <sub>6</sub><br>MW 338.848                 | 15.84                  | Aqueous isopropanol;<br>Isopropanol;<br>Hexane | <u>339</u> [M <sup>+</sup> ]; 303 (M <sup>+</sup> -1Cl); 267 (M <sup>+</sup> -2Cl); 230 (M <sup>+</sup> -3Cl)                                                           |
| PP-5<br>C <sub>10</sub> Cl <sub>5</sub> H <sub>10</sub> O <sub>2</sub><br>MW 339.43  | 17.35                  | Aqueous Isopropanol                            | <u>339</u> [M <sup>+</sup> ]; 303 (M <sup>+</sup> -1Cl); 267 (M <sup>+</sup> -2Cl); 238 (M <sup>+</sup> -2Cl-COH)                                                       |
| PP-6<br>C <sub>10</sub> Cl <sub>5</sub> H <sub>10</sub> O <sub>2</sub><br>MW 339.43  | 17.41                  | Aqueous Isopropanol                            | <u>339</u> [M <sup>+</sup> ]; 303 (M <sup>+</sup> -1Cl); 267 (M <sup>+</sup> -2Cl); 238 (M <sup>+</sup> -2Cl-COH)                                                       |
| PP-7                                                                                 | 18.66                  | Aqueous Isopropanol                            | Unidentified : 385, 347, 313, 197, 162, 128, <u>59</u> , 43                                                                                                             |
| PP-8                                                                                 | 18.86                  | Aqueous Isopropanol                            | Unidentified : 385, 347, 313, 197, 162, 128, <u>59</u> , 43                                                                                                             |

<sup>a</sup>Underlined mass is the base peak



**Fig. 3.** Photodegradation products formed in the three media: **PP-3** in aqueous isopropanol (●), isopropanol (■) and hexane (▲); **PP-4** in aqueous isopropanol (○), isopropanol (□) and hexane (△)

Figure 4 compares the mass spectra of PP-3 and PP-4 with the mass spectrum of the parent compound. PP-3, a compound with one Cl atom less than *cis*-chlordane, is proposed to have the molecular formula  $C_{10}Cl_7H_5$  with two possible structural isomers, i.e., *cis*-chlordane is monodechlorinated in C-1 or C-2. PP-4 has a molecular ion of 339 (base peak), which is two Cl atoms less than chlordane and one Cl atom less than PP-3. PP-4 is proposed to be a compound of molecular formula  $C_{10}Cl_6H_6$ . PP-4 is suggested to be a structural isomer of chlordene. The mass spectrum of PP-4 is different from the mass spectrum of chlordene found in the NIST spectral library. Although chlordene also has a molecular ion of mass 339, its base peak is  $m/z$  66. Chlordene has a double bond in C-2 and C-3. PP-4, therefore, is possibly an isomer with a double bond in C-1 and C-2.

Two degradation products were found in both aqueous isopropanol and isopropanol solutions (Figure 5). The peaks at 15.42 min (PP-1) and 15.72 min (PP-2) have a similar mass spectrum (Figure 6) and fragmentation pattern. The base peak of these photodegradation products was 238, suggesting an oxygenated molecule. Mass 238 is proposed to be a fragment of the molecular ion 374 minus two O atoms and three Cl atoms. The difference between masses 267 and 238 (Table 1) may be due to the removal of COH. PP-1 and PP-

2 are proposed to be structural isomers of a compound with  $C_{10}Cl_6H_8O_2$  as molecular formula and 372.864 amu as molecular mass. High resolution GC-MS of the concentrated irradiated solutions gave molecular ions of masses 372.9619, 273.9784, and 274.9603. PP-1 and PP-2 have  $m/z$  374 as molecular ion in the EI mass spectra of low resolution GC-MS (an example is given in Figure 6). GC-MS, however, does not provide information on the exact position of the hydroxyl groups. PP-1 or PP-2 can be an isomer of the other where the hydroxyl groups are in C-1 and C-2, C-2 and C-3, or C-1 and C-3. One of these isomers can be 1,2-dihydroxydihydrochlordene. 1,2-Dihydroxydihydrochlordene has been reported as a metabolic by-product of chlordane and heptachlor in animal studies [24]. Hydroxylation at C-5 or C-6 is also possible. And although PP-1 and PP-2 are assumed to be isomers, their formation was found to be affected by the reaction medium. These photoisomers were formed during the first 60 min of UV irradiation in aqueous isopropanol but were detected only after over 240 min of UV exposure in pure isopropanol.

Figure 7 shows the formation of four more main degradation products in aqueous isopropanol medium. The compounds that eluted at 17.35 min (PP-5) and 17.41 min (PP-6) have a similar fragmentation pattern and a common mass spectrum (Figure 8). PP-5 and PP-6 gave a molecular ion of mass 339 suggesting a molecule with a chemical formula  $C_{10}Cl_5H_{10}O_2$  and molecular mass of 339.43 amu. PP-5 or PP-6 is one chlorine atom less than PP-1 and PP-2 where dechlorination can occur at C-5 or C-6. The prominent fragment of mass 238 common to both is proposed to be that of the molecular ion minus two O atoms and two Cl atoms. The difference between masses 267 and 238 may also be due to COH dissociation. PP-5 and PP-6, therefore, may be structural isomers. Two additional degradation products found at 18.66 min (PP-7) and 18.86 min (PP-8) also have a similar mass spectrum with a base peak of 59 (Table 1). Their chemical structures, however, remain unknown and further elucidation is needed. Once formed during UV irradiation, PP-5 and PP-6 as well as PP-7 and PP-8 remained detected in aqueous isopropanol throughout the irradiation experiment.

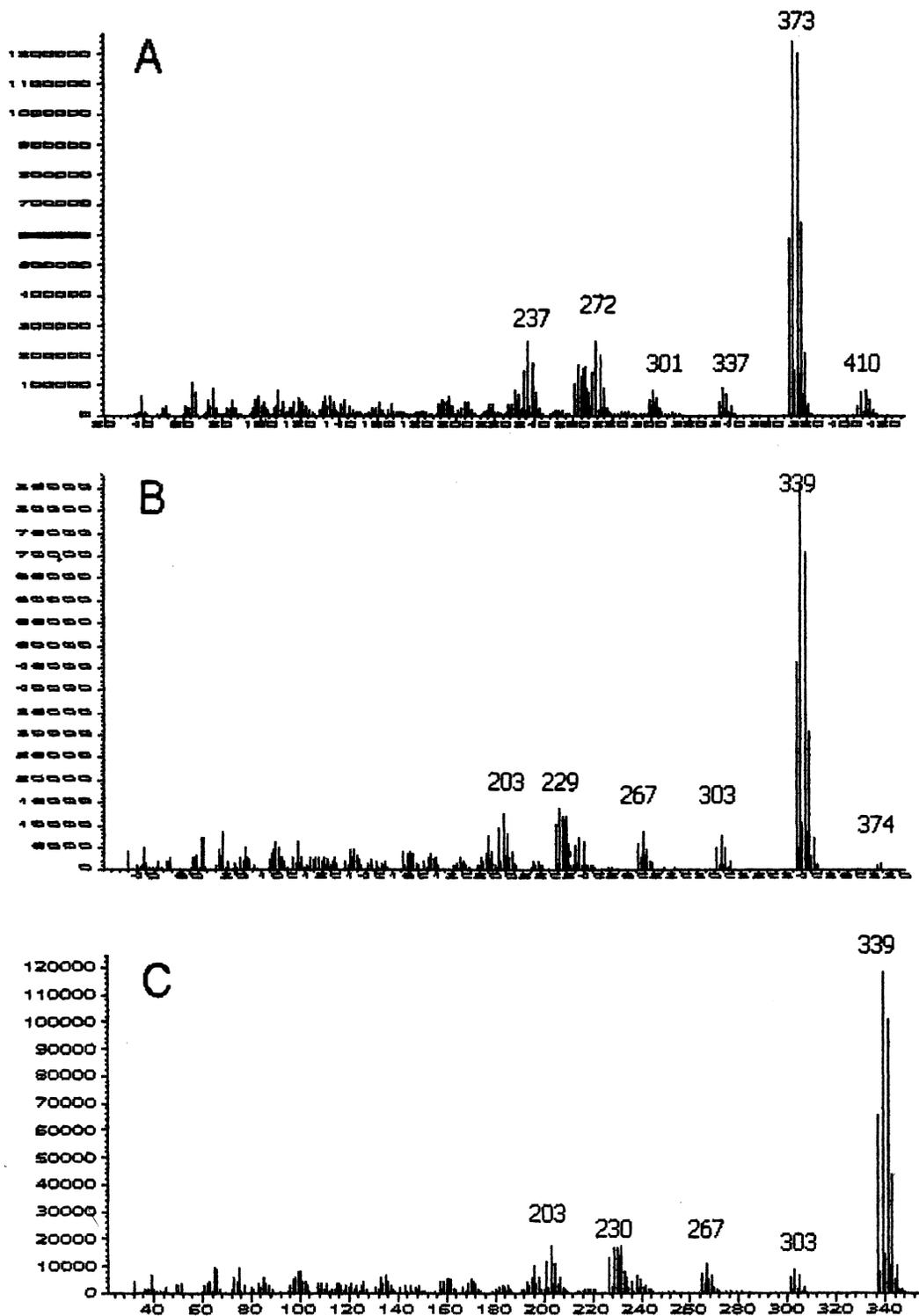


Fig. 4. Mass spectra of *cis*-Chlordane,  $C_{10}Cl_8H_6$  (A), *PP-3*,  $C_{10}Cl_7H_5$  (B), and *PP-4*,  $C_{10}Cl_6H_6$  (C)

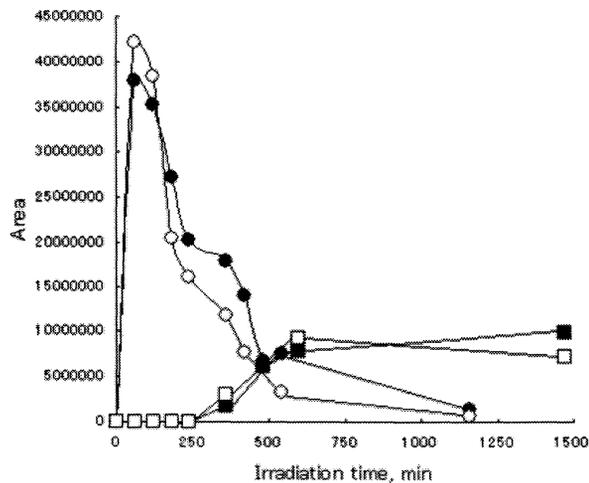


Fig. 5. Photodegradation products in polar media: **PP-1** in aqueous isopropanol (●) and in isopropanol (■); **PP-2** in aqueous isopropanol (○) and in isopropanol (□)

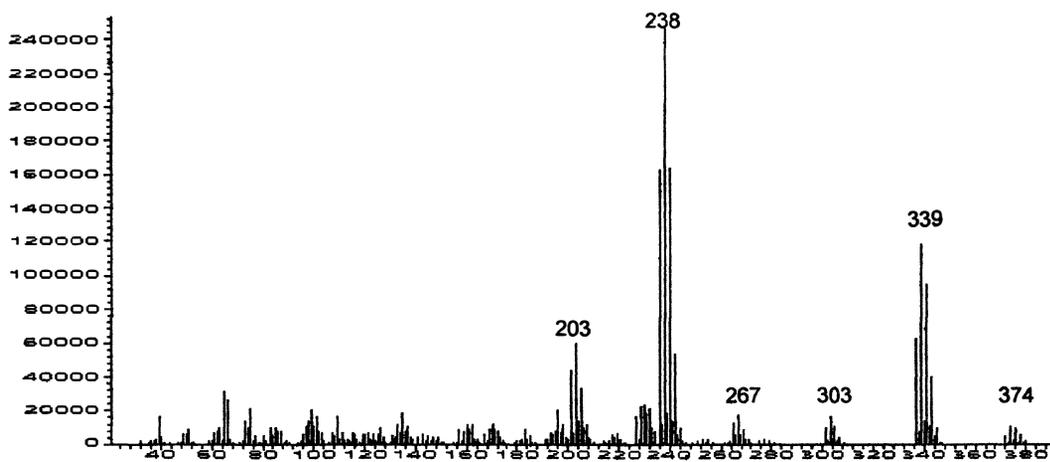


Fig. 6. Mass spectrum of  $C_{10}Cl_6H_8O_2$  (**PP-1** at RT 15.42 min and **PP-2** at RT 15.72 min)

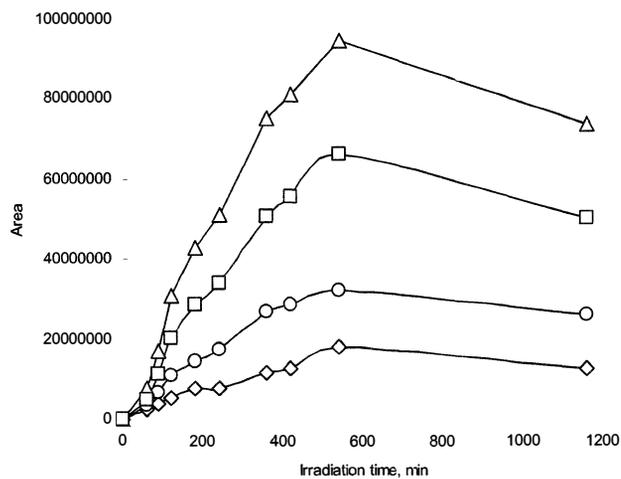


Fig. 7. Other photodegradation products formed in aqueous isopropanol: **PP-5** (◇); **PP-6** (○); **PP-7** (Δ); **PP-8** (□)

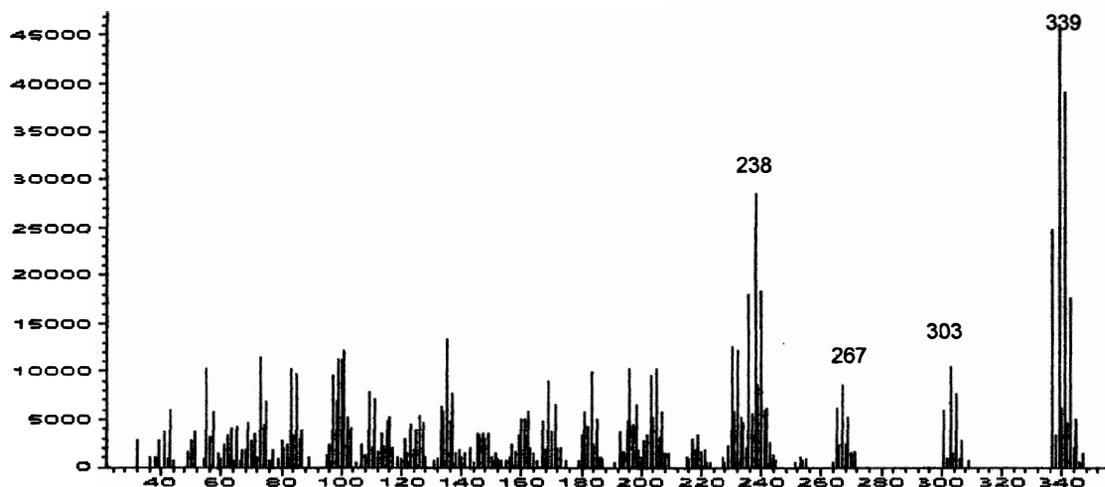


Fig. 8. Mass spectrum of  $C_{10}Cl_5H_{10}O_2$  (**PP-5** at RT 17.35 min and **PP-6** at RT 17.41 min)

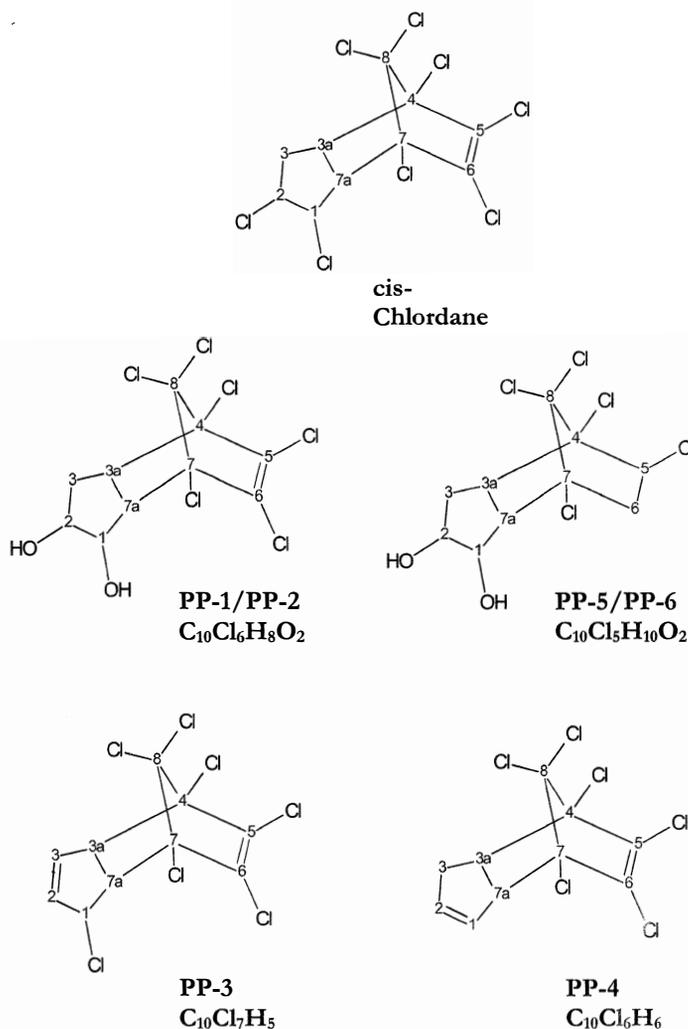


Fig. 9. Structures of *cis*-chlordane (1,2,4,5,6,7,8,8a-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methano-1H-indene) and the proposed photodegradation products

Figure 9 shows the molecular structures of *cis*-chlordane and of the proposed degradation products in the three media. In hexane, PP-3 and PP-4 resulted from the dechlorination of *cis*-chlordane. PP-3 was further dechlorinated to PP-4. In isopropanol and aqueous isopropanol, PP-3 and PP-4 may transform to produce the oxygenated compounds PP-1, PP-2, PP-5 or PP-6. Except for PP-4 that was formed in aqueous isopropanol, these photodegradation products persisted in the solutions after over 1000 min of UV irradiation. The proposed structures require confirmation by comparison with mass spectral data of synthesized standards of these compounds. Further study is also needed to assign the isomers where isolated and purified materials are needed for additional spectrometric analyses.

## CONCLUSIONS AND RECOMMENDATIONS

This study provides a basis for predicting the transformation products of the POPs pesticide *cis*-chlordane in aqueous isopropanol, isopropanol and hexane when treated with UV radiation. Based on the proposed structures of the photoproducts, the degradation process involved dechlorination and oxidation. In hexane, dechlorinated forms of *cis*-chlordane ( $C_{10}Cl_7H_5$  and  $C_{10}Cl_6H_6$ ) were produced. In isopropanol and in aqueous isopropanol, the photoproducts include the oxygenated compounds  $C_{10}Cl_6H_8O_2$  and  $C_{10}Cl_5H_{10}O_2$ . These proposed photoproducts, however, require confirmation and further study. NMR and IR measurements are recommended to validate the proposed structures. A large scale irradiation experiment can be set up in order to collect enough samples where these photoproducts can be isolated, purified and subjected to NMR and IR studies.

At this point, it can be concluded that the proposed photodegradation products are relatively stable and they persist in the three solvents after over 16 h of UV light exposure. The UV degradation of *cis*-chlordane is also observed to be affected by the polarity of the medium. The degradation rate increases as solvent polarity increases, i.e., hexane < isopropanol < aqueous isopropanol.

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