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Su-Cai Yang\textsuperscript{a} \textsuperscript{b}, Mei Lei\textsuperscript{a} & Tong-Bin Chen\textsuperscript{a}

\textsuperscript{a} Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

\textsuperscript{b} Beijing Key Laboratory of Remediation of Industrial Pollution Sites, Environmental Protection Research Institute of Light Industry, Beijing, China

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Effect of Surfactant Tween 80 on the Anaerobic Degradation and Desorption of HCHs and DDX in Aged Soil under Saturated Condition with Low Liquid/Solid Ratio

SU-CAI YANG,1,2 MEI LEI,1 AND TONG-BIN CHEN1

1Center for Environmental Remediation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China
2Beijing Key Laboratory of Remediation of Industrial Pollution Sites, Environmental Protection Research Institute of Light Industry, Beijing, China

The application of surfactant Tween 80 was investigated to accelerate the anaerobic degradation of HCHs (α-, β-, γ- and δ-hexachlorocyclohexane) and DDX (p,p'-DDT, o,p'-DDT, p,p'-DDE and p,p'-DDD) in aged soil from a former organochlorine pesticide manufacturing plant under saturated condition with low liquid/solid ratio (liquid/solid ratio = 0.50). The surfactant Tween 80 did not facilitate the degradation of HCHs and DDX in the soil used in this experiment. Subsequent desorption experiment results also showed that the surfactant Tween 80 did not increase the pollutant desorption from the soil. The results in this study are not in accordance with the results reported in previous literature. This difference might be due to the fact that the soils used in this experiment were polluted by HCHs and DDX for more than 20 years, and soil aging reduced the desorption of HCHs and DDX in soil. Furthermore, the surfactants might be adsorbed by soils in low liquid/solid ratio condition.

Keywords: Contaminated site, bioremediation, organochlorine pesticides, surfactant Tween 80

Introduction

Organochlorine pesticides (OCPs), such as lindane and DDT (1,1,1-trichloro-2,2-bis (p-chlorophenyl)ethane), have been used for the control of agricultural pests (Li, 1999; Eggen and Majcherczyk, 2006). The technical grade of lindane also contains α-, β-, and δ-HCH isomers as by-products (Phillips et al., 2006). DDD (1,1-dichloro-2,2-bis (p-chlorophenyl)ethane) and DDE (1,1-dichloro-2,2-bis (p-chlorophenyl) ethylene) are obtained as impurities during the manufacture of DDT and also as stable transformation products from biotic and abiotic processes (Foght et al., 2001). DDT, DDE, and DDD are collectively referred to as DDX. Organochlorine pesticides (OCPs) have been recognized as a potential health risk because of their bioaccumulation, recalcitrance to degradation, and potential toxicity to...
humans and wildlife (Jones and de Voogt, 1999; Turusov et al., 2002; Behrooz et al., 2009; Trejo-Acevedo et al., 2009). Therefore, the production of organochlorine pesticides was banned in many countries before the 1990s (Voldner and Li, 1995; Li, 1999; Wang et al., 2010). However, concentrations of HCHs and DDX in soils in many former organochlorine pesticides manufacturing plants are still high due to spills, discharges, or leaking storage tanks (Phillips et al., 2006; Yang et al., 2009; Yang et al., 2010).

To remediate and restore the functions of soil polluted by HCHs and DDX, effective technologies are necessary. The biodegradation of pesticides offers an attractive approach to the removal of these compounds from contaminated sites (Foght et al., 2001; Phillips et al., 2005). However, the bioavailability of pesticides in soils is decreased by physical limitations such as adsorption to mineral surfaces or soil organic matter (to various degrees of reversibility), and by the limited aqueous solubility of the chemical that reduces its diffusion in pore water (Foght et al., 2001). The adsorption to and within soil particles plays a major role in reducing the bioavailability of HCHs and DDX (Foght et al., 2001; Quintero et al., 2005). Limited bioavailability might impede the biodegradation of HCHs and DDX in soils (Foght et al., 2001; Phillips et al., 2005).

Surfactants consist of organic molecules with hydrophobic and hydrophilic parts and can interact with polar and nonpolar surfaces (Sánchez-Camazano et al., 2003). Surfactants exist solely as monomers above a critical aqueous concentration, which is specific for each surfactant monomer, called critical micellar concentration (CMC); the surfactant monomers are aggregated in solution to form entities made up of a hydrophobic core and a hydrophilic shell. These micelles result in the increased pseudo-water-solubilities of hydrophobic organic compounds (HOCs), thereby increasing the concentration gradient and mass transfer rates (Mulder et al., 1998; Volkering et al., 1995). Some studies have observed that surfactants can facilitate the solubility and degradation of HCHs and DDT in the water and soil freshly spiked with this pesticide under a large liquid/solid ratio (Kile and Chiou, 1989; You et al., 1996; Sayles et al., 1997; Quintero et al., 2005). However, the potential of surfactant Tween 80 to stimulate the degradation of HCHs and DDX in contaminated-site soils under saturated condition with low liquid/solid ratio has not been fully explored.

Significant differences exist between the soil freshly spiked with OCPs and the contaminated-site soil that has been polluted by OCPs for several years. The OCPs, such as HCHs and DDX, in contaminated-site soil may have become less bioavailable after being naturally aged for many years (Singh and Agarwal, 1992; Quintero et al., 2005). The soils from former OCP manufacturing plants may also be impacted by more than one contaminant. Co-contaminants may complicate biodegradation (Foght et al., 2001). They provide more readily utilized substrates for the micro flora, which can divert the enzymatic activity from the contaminant of concern. Furthermore, they may have specific or non-specific toxic effects on the soil micro flora and may affect the solubility or adsorption of the contaminant of concern (Foght et al., 2001).

This study aimed to investigate the effect of the surfactant Tween 80 on the anaerobic degradation and desorption of HCH isomers (α, β, γ, δ-HCH) and DDX (DDT, DDD, DDE) in soil from a former OCP manufacturing plant under saturated condition with low liquid/solid ratio (liquid/solid ratio = 0.50). Zerovalent iron (Fe₀) was added to soil because it is a good reducing agent and can generate a reduced environment in soils (Yang et al., 2010). Many pesticides, such as β-HCH and DDX, are normally considered persistent in aerobic environments, and not persistent under anaerobic conditions (Aislabie et al., 1997; Van Eekert et al., 1998).
Degradation of HCHs and DDX with Tween 80

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Molecular weight</th>
<th>Vapor pressure (Pa)</th>
<th>Solubility in water (g/L)</th>
<th>Henry constant (Pa m³ mol⁻¹)</th>
<th>Octanol water coefficient (log Kow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-HCH</td>
<td>290.8</td>
<td>5.3 × 10⁻³</td>
<td>1.6 × 10⁻³</td>
<td>4.0 × 10⁻⁴</td>
<td>3.77</td>
</tr>
<tr>
<td>β- HCH</td>
<td>290.8</td>
<td>4.3 × 10⁻⁵</td>
<td>3.2 × 10⁻⁴</td>
<td>1.6 × 10⁻⁵</td>
<td>3.85</td>
</tr>
<tr>
<td>γ- HCH</td>
<td>290.8</td>
<td>2.9 × 10⁻³</td>
<td>6.2 × 10⁻³</td>
<td>5.6 × 10⁻⁵</td>
<td>3.66</td>
</tr>
<tr>
<td>δ- HCH</td>
<td>290.8</td>
<td>2.3 × 10⁻³</td>
<td>9.0 × 10⁻³</td>
<td>7.3 × 10⁻²</td>
<td>4.14</td>
</tr>
<tr>
<td>p,p'/DDT</td>
<td>354.5</td>
<td>2.5 × 10⁻⁵</td>
<td>3.4 × 10⁻⁶</td>
<td>1.1 × 10⁻³</td>
<td>6.20</td>
</tr>
<tr>
<td>p,p'/DDDE</td>
<td>318.0</td>
<td>9.9 × 10⁻⁴</td>
<td>2.4 × 10⁻⁵</td>
<td>4.1 × 10⁻³c</td>
<td>5.76</td>
</tr>
<tr>
<td>p,p'/DDDD</td>
<td>320.1</td>
<td>1.0 × 10⁻⁴</td>
<td>1.0 × 10⁻⁴</td>
<td>6.4 × 10⁻¹</td>
<td>6.02</td>
</tr>
</tbody>
</table>

aFrom Manz et al. (2001).
bData determined at 20°C, unless stated otherwise.
cDetermined at 25°C.

Materials and Methods

Chemicals and Reagents

The standard solutions of organochlorine pesticides, including α-, β-, γ- and δ-HCH [hexachlorocyclohexane], p,p'-DDT [1,1,1,-trichloro-2,2-bis(p-chlorophenyl)ethane], o,p'-DDT [1,1,1,-trichloro-2-(p-chlorophenyl)-2-(o-chloro-phenyl)ethane], p,p'-DDD [1,1-dichloro-2,2-bis (p-chlorophenyl)-ethane], p,p'-DDE [1,1-dichloro-2,2-bis (p-chlorophenyl)ethylene] and pentachloronitrobenzene (PCNB), were purchased from the National Research Center for Certified Reference Materials of China. Hexane and dichloromethane (HPLC-graded) were offered by Tedia Company, USA. All other solvents were of the analytical grade and were re-distilled before use. Anhydrous sodium sulphate (Na₂SO₄, AR, Beijing Chemical Reagent Plant, P.R. China) was oven-dried at 450°C for 6 h to act as a desiccant. Silica gel (80 mesh, Dalian Chemical and Physical Institute, P.R. China) and alumina (E. Merck Company, 100 mesh) were activated in an oven at 180°C and 250°C, respectively, then deactivated by adding 3% deionized water. Zerovalent iron (Fe⁰) (size < 100 mesh, 98% of total iron) and surfactant Tween 80 were purchased from Beijing Chemical Factory, China. The molecular weight and critical micellar concentrations of the surfactant Tween 80 are 1310 g mol⁻¹ and 0.04 g L⁻¹, respectively. The physicochemical properties of hexachlorocyclohexane isomers (α, β, γ, δ-HCH) and DDX (DDT, DDD, DDE) are presented in Table 1.

Soil Samples

To remediate a former organochlorine pesticide-contaminated site in Beijing, China, about 10⁵ m³ of heavily organochlorine pesticide-contaminated soil was removed from the contaminated site in 2008 and stored in a storehouse in Beijing, China. In this study, about 10 kg soil was sieved (2 mm) and homogenized. The soil was characterized as 44.88% sand, 51.42% silt, and 3.7% clay, with pH 8.14, a total organic carbon of 11.4 g kg⁻¹, a
Table 2

Initial concentrations of HCHs and DDX in the soil used in this study (n = 15)

<table>
<thead>
<tr>
<th>Compound</th>
<th>mg kg(^{-1}) (d.w.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-HCH</td>
<td>2.30 ± 0.37</td>
</tr>
<tr>
<td>β-HCH</td>
<td>25.22 ± 1.77</td>
</tr>
<tr>
<td>γ-HCH</td>
<td>1.26 ± 0.26</td>
</tr>
<tr>
<td>δ-HCH</td>
<td>4.12 ± 0.6</td>
</tr>
<tr>
<td>p,p′-DDT</td>
<td>25.17 ± 1.70</td>
</tr>
<tr>
<td>o,p′-DDT</td>
<td>6.67 ± 0.55</td>
</tr>
<tr>
<td>p,p′-DDD</td>
<td>7.91 ± 0.93</td>
</tr>
<tr>
<td>p,p′-DDE</td>
<td>4.56 ± 0.58</td>
</tr>
</tbody>
</table>

Total nitrogen of 0.79 g kg\(^{-1}\), and a moisture of 1.5%. The soil was sampled from each treatment (three replicates) on day 0 of the incubation to measure the initial concentrations of HCHs and DDX in soil (Table 2).

**Experimental Set-Up**

To evaluate the effect of the surfactant Tween 80 on the HCHs and DDX biodegradation, biodegradation experiments were conducted in 250 mL conical flasks with 100 g of fresh soil (wet weight) and 0.5 g zerovalent iron (Fe\(^0\)) after intermixing thoroughly. Forty-eight mL water or Tween 80 solution (with different concentration of Tween 80) was transferred to the flasks, which were then tightly closed. The soil pore water/soil ratio equaled 0.50 after water or Tween 80 solution was added to each flask. Five treatments were then initiated, as follows: (1) no Fe\(^0\) and no Tween 80; (2) 0.5% (w/w) Fe\(^0\) and no Tween 80; (3) 0.5% (w/w) Fe\(^0\) and Tween 80 (1 CMC, critical micellar concentration of Tween 80 in soil pore water); (4) 0.5% (w/w) Fe\(^0\) and Tween 80 (5 CMC); (5) 0.5% (w/w) Fe\(^0\) and Tween 80 (20 CMC). Each treatment included three replicates. The soil samples in the conical flasks were incubated at 30°C in the dark. The soil was sampled from each treatment at 0, 10, 20, and 30 days of incubation to measure the concentrations of HCHs and DDX in soil. The oxidation-reduction potential was measured after 0, 1, 3, 5, 10, 20, and 30 days of incubation by additional treatments.

To evaluate the effect of Tween 80 on the HCHs and DDX desorption, desorption experiments were conducted in a centrifuge glass tube in three triplicates. Fresh soil (60 g wet weight; intermixed thoroughly) and Tween 80 solution (29 mL; with 500 mg/L HgCl\(_2\)) with different concentrations of Tween 80 (0, 1, 5, and 20 CMC) were transferred to two centrifuge glass tubes (liquid/solid ratio = 0.50). Four treatments were then initiated, as follows: (1) control (no Tween 80); (2) Tween 80 (1 CMC); (3) Tween 80 (5 CMC); (4) Tween 80 (20 CMC). The centrifuge glass tube was hermetically sealed and incubated at 30°C in the dark for 48 h to reach soil-liquid equilibrium. The centrifuge glass tubes were centrifuged (3000 r/min) for three times to obtain soil pore water. The combined soil pore water was filtered under vacuum through pre-ashed glass fiber filters (Whatman, GF/F) to obtain dissolved samples. The centrifuged soil was wrapped in pre-cleaned aluminum foil and was immediately stored at −20°C until analysis.
Degradation of HCHs and DDX with Tween 80 719

Extraction and Analytical Procedures

Ultrasonic extraction was applied to extract the organochlorine pesticide from the soil (USEPA, 2000). Briefly, 1g of homogenized and freeze-dried soil was placed in 50 mL centrifuge tubes and 30 mL of dichloromethane/hexane (1:1, v/v) was added. The sample was extracted three times by ultrasonication for 60 minutes, 30 minutes, and 30 minutes, respectively, in an ultrasonic cleaning bath (400 W average power output and mean operating frequency of 40 kHz). Soil pore water samples were extracted using a liquid-liquid extraction (LLE) method (Fernandez et al., 1996). Briefly, the soil pore water sample was extracted successively with three volumes of 30 mL of a dichloromethane. The extract was collected, passed through Na₂SO₄, and separated by centrifugation at 4000 rpm for 15 min to obtain clear organic supernatants. The combined extracts were concentrated to about 3 mL in an eggplant-type bottle with a vacuum rotary evaporator at a temperature below 39°C. An additional 10 mL of hexane was added to the eggplant-type bottle and the combined extracts were again concentrated to about 3 mL in the eggplant-type bottle, and then the hexane extracts were transferred to a 1:2 alumina/silica gel glass column to be purified and fractionated. The column was eluted with 15 mL of hexane and the eluate was discarded. The second organochlorine pesticide-containing fraction was eluted with 70 mL of dichloromethane/hexane (3:7, v/v). The eluate-containing organochlorine pesticide was diluted with hexane to fit the GC calibration range.

The identification and quantification of organochlorine pesticide in the extracts were accomplished by a gas chromatograph equipped with an electron capture detector (ECD) (HP 5890 series II, Agilent). The capillary column was HP-5, 30 m long × 0.32 mm width × 0.25 μm film thickness. The carrier gas was nitrogen (purity = 99.999%). The injector and detector temperature were 250°C and 300°C, respectively. The oven temperature program consisted of an initial temperature of 60°C for 1 min, which was increased at a rate of 20°C min⁻¹ to 140°C, held for 5 min, and then raised at a rate of 5°C min⁻¹ up to 235°C, and held for 2 min. The injection volume was 1 μL in the splitless mode. The quantification was determined by internal calibration. The quantification of organochlorine pesticide was accomplished by an eight-point internal calibration curve using peak area. The internal standard for determining the OCPs was pentachloronitrobenzene (PCNB).

Results and Discussion

The results of this study show that zero-valent iron (Fe⁰) could facilitate the degradation of β-HCH, p,p’-DDT, o,p’-DDT, and p,p’-DDE, but show little effect on the degradation of α-HCH, γ-HCH and δ-HCH (Figures 1 and 2). This could be attributed to the characteristics that α-HCH, γ-HCH, and δ-HCH might biodegrade under both aerobic condition and anaerobic conditions, whereas the biodegradation of β-HCH, p,p’-DDT, o,p’-DDT, and p,p’-DDE needs anaerobic conditions (Foght et al., 2001; Phillips et al., 2005; Yang et al., 2010). In this study, Fe⁰ had a significant effect on the oxidation-reduction potential. The oxidation-reduction potential of the treatment with Fe⁰ decreased rapidly from a level of +400 mV to less than −200 mV, and Fe⁰ generated a reduced (electron-rich) environment in soils.

In most biodegradation pathways, DDT is reductively dechlorinated to DDD under reducing conditions (reviewed by Aislabie et al., 1997; Foght et al., 2001). Under anaerobic conditions, DDD may be further metabolized. However, DDD accumulation was found in this study. The results reported in this work for the DDD accumulation are in agreement with other studies (Burge, 1971; Boul, 1996). The transformation of DDT to DDD by reductive
dechlorination might be an important factor. The acclimation time for microorganisms and the temporary inhibiting effect of the increased DDD concentration might be another important factor (Eggen and Majcherczyk, 2006; Yao et al., 2006). The proposed pathway for the anaerobic transformation of DDT by bacteria and fungal showed that DDD was reductively dechlorinated to 2,2′-bis (4-chlorophenyl)ethylene (DDNU), which was successively oxidized to 2,2′-bis (4-chlorophenyl)ethanol (DDOH) and bis (4-chlorophenyl)-acetic acid (DDA). The latter was decarboxylated to bis (4-chlorophenyl) methane (DDM). DDM was oxidized to 4,4′-dichlorobenzophenone (DBP), which was not further metabolized under anaerobic conditions (Foght et al., 2001). Alternating anaerobic and aerobic incubation conditions can enhance DDX biodegradation by promoting the reductive dechlorination of DDT to DPB with subsequent aerobic aromatic ring cleavage (Foght et al., 2001).

The percentage degradations of $\alpha$-HCH, $\beta$-HCH, $\gamma$-HCH, $\delta$-HCH, p,p$'$-DDT, o,p$'$-DDT, and p,p$'$-DDE in the treatment with 0.5% Fe$^0$ (w/w) and without surfactant Tween 80 were 65%, 27%, 85%, 51%, 58%, 60%, and 38%, respectively. The percentage degradation ranges of $\alpha$-HCH, $\beta$-HCH, $\gamma$-HCH, $\delta$-HCH, p,p$'$-DDT, o,p$'$-DDT, and p,p$'$-DDE in treatment with 0.5% Fe$^0$ (w/w) and surfactant Tween80 (1 CMC, 5 CMC, 20 CMC) were 52% to 68%, 20% to 27%, 71% to 79%, 52% to 62%, 47% to 57%, 51% to 60%, and 22% to 34%, respectively. In this experiment, zerovalent iron could facilitate the degradation of

**Figure 1.** Time course of HCH concentrations as affected by zerovalent iron (Fe$^0$) alone or in combination with Tween 80: (□) soil; (○) soil+0.5%(w/w) Fe$^0$; (△) soil+0.5%(w/w) Fe$^0$+Tween 80 (1 CMC); (▽) soil+0.5%(w/w) Fe$^0$+Tween 80 (5 CMC); (◁) soil+0.5%(w/w) Fe$^0$+Tween 80 (20 CMC); average n = 3 ± s.d.
Degradation of HCHs and DDX with Tween 80

Figure 2. Time course of DDX concentrations as affected by zerovalent iron (Fe⁰) alone or in combination with Tween 80: (□) soil; (○) soil+0.5%(w/w) Fe⁰; (△) soil+0.5%(w/w) Fe⁰+Tween 80 (1 CMC); (▽) soil+0.5%(w/w) Fe⁰+Tween 80 (5 CMC); (◁) soil+0.5%(w/w) Fe⁰+Tween 80 (20 CMC); average n = 3 ± s.d.

β-HCH, p,p’-DDT, o,p’-DDT, and p,p’-DDE. However, little effect of surfactant Tween 80 on the degradation of β-HCH, p,p’-DDT, o,p’-DDT, p,p’-DDE was observed (Figures 1 and 2), which was not in accordance with the results reported in previous literature (You et al., 1996; Quintero et al., 2005).

That surfactants might be adsorbed by soils in low liquid/solid ratio condition might be an important factor. The application of surfactant Tween 80 was investigated to accelerate the anaerobic degradation of HCHs and DDX in soil from a former organochlorine pesticides-manufacturing plant under saturated condition with low surfactant Tween 80 solution/solid ratio (liquid/solid ratio = 0.50). In contrast, the surfactant Tween 80 solution/solid ratio was higher than 10 in previous studies (You et al., 1996; Quintero et al., 2005). Furthermore, soil aging reducing the desorption of HCHs and DDX in soil might be another important factor. The soils used in previous studies (You et al., 1996; Quintero et al., 2005) were freshly spiked with OCPs and had soil aging of less than three months. Soil used in this experiment was obtained from a former organochlorine pesticides-manufacturing plant in China, which was polluted for more than 20 years. DDX and HCHs in the contaminated-site soil might have become less available because the bioavailability of DDT and HCHs can diminish with time (Singh and Agarwal, 1992; Quintero et al., 2005).

Desorption experiments were conducted in this study to evaluate the effect of Tween 80 on HCH and DDX desorption. The ratios of the amount of pesticides in soil pore water...
Table 3

Ratio of the amount of pesticides in soil pore water to the amount of pesticides in soil

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>0 CMC</th>
<th>1 CMC</th>
<th>5 CMC</th>
<th>20 CMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-HCH</td>
<td>10^{-3}</td>
<td>7.99 ± 1.67 a</td>
<td>7.54 ± 0.81 a</td>
<td>6.10 ± 1.13 a</td>
</tr>
<tr>
<td>β-HCH</td>
<td>10^{-3}</td>
<td>2.76 ± 0.41 a</td>
<td>2.87 ± 0.33 a</td>
<td>2.77 ± 0.48 a</td>
</tr>
<tr>
<td>γ-HCH</td>
<td>10^{-3}</td>
<td>6.03 ± 0.69 a</td>
<td>6.11 ± 0.45 a</td>
<td>5.41 ± 1.59 a</td>
</tr>
<tr>
<td>δ-HCH</td>
<td>10^{-3}</td>
<td>4.75 ± 0.64 a</td>
<td>4.40 ± 0.05 a</td>
<td>4.59 ± 0.86 a</td>
</tr>
<tr>
<td>p,p′-DDE</td>
<td>10^{-5}</td>
<td>4.15 ± 0.62 a</td>
<td>4.83 ± 0.64 a</td>
<td>4.25 ± 1.09 a</td>
</tr>
<tr>
<td>p,p′-DDD</td>
<td>10^{-4}</td>
<td>2.34 ± 0.05 a</td>
<td>2.74 ± 0.66 a</td>
<td>2.90 ± 1.01 a</td>
</tr>
<tr>
<td>o,p′-DDT</td>
<td>10^{-5}</td>
<td>4.75 ± 0.03 a</td>
<td>5.76 ± 1.05 a</td>
<td>4.48 ± 0.87 a</td>
</tr>
<tr>
<td>p,p′-DDT</td>
<td>10^{-5}</td>
<td>4.52 ± 0.33 a</td>
<td>5.83 ± 1.31 a</td>
<td>5.74 ± 1.81 a</td>
</tr>
</tbody>
</table>

CMC: Critical micellar concentration.

For each compound, the values in a file followed by the same letter are not significantly different (P < 0.05).

The ratio of the amount of pesticides in soil pore water to the amount of pesticides in soil are presented in Table 3. The average ratios of the amount of α-HCH, β-HCH, γ-HCH, δ-HCH, p,p′-DDE, p,p′-DDD, o,p′-DDT, and p,p′-DDT in soil pore water to the amount of pesticides in soil in the treatment without surfactant Tween 80 were 7.99 × 10^{-3}, 2.76 × 10^{-3}, 6.03 × 10^{-3}, 4.75 × 10^{-3}, 4.15 × 10^{-5}, 2.34 × 10^{-4}, 4.75 × 10^{-5}, and 4.52 × 10^{-5}, respectively. The average ratios of the amount of α-HCH, β-HCH, γ-HCH, δ-HCH, p,p′-DDE, p,p′-DDD, o,p′-DDT, and p,p′-DDT in soil pore water to the amount of pesticides in soil in the treatment with surfactant Tween 80 (1, 5, 20 CMC) were 6.02 to 7.54 × 10^{-3}, 2.71 to 2.87 × 10^{-3}, 4.99 to 6.11 × 10^{-3}, 4.40 to 4.61 × 10^{-3}, 4.25 to 4.83 × 10^{-5}, 2.72 to 2.90 × 10^{-4}, 4.48 to 5.76 × 10^{-5}, and 5.74 to 5.83 × 10^{-5}, respectively. No difference was found for the desorption profiles of HCHs and DDX in the absence and presence of surfactant Tween 80 (0 CMC, 1 CMC, 5 CMC, 20 CMC) (P < 0.05). Additional surfactant Tween 80 did not increase the pollutant desorption from the soil, which was polluted by these pesticides for more than 20 years.

The effect of soil aging on HCH and polycyclic aromatic hydrocarbon desorption has been reported (Dictor et al., 2003; Quintero et al., 2005). A significant decrease of the pollutant concentration in the aqueous phase has been observed for the soil with higher time exposures in the desorption assays (Quintero et al., 2005). Desorption has been assumed to be the limiting step in the degradation of the pollutants present in soil (Harms and Bosma, 1997), and some authors have observed that the degradation of pollutants is largely affected by desorption (Rijnaarts et al., 1990; You et al., 1996; Quintero et al., 2005). Some studies observed that surfactants can facilitate the degradation of HCHs and DDT in water and soil freshly spiked with this pesticide (Quintero et al., 2005; You et al., 1996). However, surfactant Tween 80 did not facilitate the degradation of δ-HCH, p,p′-DDT, o,p′-DDT, and p,p′-DDE in the contaminated-site soils because of its insignificant effect on the desorption of HCHs and DDX.

**Conclusion**

The effect of surfactant Tween 80 on the anaerobic degradation of HCHs and DDX was investigated in soil from a former organochlorine pesticides-manufacturing plant under...
Degradation of HCHs and DDX with Tween 80

Degradation of HCHs and DDX with Tween 80 was observed on the desorption and degradation of HCHs and DDX, which was not in accordance with the results reported in previous literature. This difference might be due to the fact that the soils used in this experiment were polluted by HCHs and DDX for more than 20 years, and soil aging reduces the desorption of HCHs and DDX in soil. Furthermore, the surfactant might be adsorbed by soil in low liquid/solid ratio condition. The reasons that surfactant Tween 80 did not increase the pollutant desorption and degradation in the soil under saturated condition with low liquid/solid ratio have to be clarified in further studies.

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