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BIODEGRADATION RATE OF CHLOROETHYLENE IN SOIL ENVIRONMENT

O. Yagi, H. Uchiyama and K. Iwasaki

The National Institute for Environmental Studies, Tsukuba, Ibaraki 305, Japan

ABSTRACT

Degradation rates of PCE and TCE were determined in lotus, rice and vegetable field soils. The lotus field soil had the highest ability to degrade tetrachloroethylene(PCE) and trichloroethylene(TCE). The values of T_{50}(50% degradation time) in L-1 lotus soil were 8 and 15 days for PCE and TCE under the substrate concentration of 5μg in 50ml of soil solution. PCE was biologically transformed to TCE in all soils. The material balance of PCE depletion and TCE production were determined. The degradation rates of PCE and TCE were significantly influenced by temperature and substrate concentration.

KEYWORDS

Biodegradation, Trichloroethylene, Tetrachloroethylene, Soil, Microcosm

INTRODUCTION

Groundwater contamination of volatile chlorinated compounds such as tetrachloroethylene(PCE), trichloroethylene(TCE) and 1,1,1-trichloroethane(TCA) was found out everywhere in Japan through the survey of Japan Environment Agency (Kawasaki, 1985). PCE and TCE are considered to be carcinogenic compounds and generally resistant to biodegradation in the environment. Therefore, Japan Environment Agency decided water quality standards of 0.1mg/l for PCE and 0.3mg/l for TCE respectively.

Recently, the biodegradation of PCE and TCE in soil has been studied. Roberts et al.(1982) determined the biodegradation of chlorinated compounds in the subsurface aquifer. Parsons et al.(1984), Kleopfer et al.(1985), Strand et al.(1986), Wilson et al.(1986), Barrio-Lage et al.(1986, 1987a, 1987b) reported the biodegradation of chlorinated ethylenes in soil. General agreement exists that the biodegradation of PCE proceeds by sequential reductive dechlorination to TCE, dichloroethylene(DCE), vinyl chloride(VC) and CO_2 in soil (Vogel et al. 1985, Belay et al. 1987).

However, little information has been published regarding the environmental factors on the biodegradation rate of PCE and TCE in soil (Uchiyama et al. 1989a, 1989b).
In this study, we constructed microcosms that simulated the groundwater environment and determine the effects of soil sources, temperature and substrate concentrations on the biodegradation rates of PCE and TCE.

MATERIALS AND METHODS

Chemicals PCE and TCE used in this study were of reagent-grade and purchased from Gaskurokogyo Co., Tokyo.

Soil samples Seven soil samples were assayed to determine their ability to degrade PCE and TCE. Three (L-1, L-2, L-3) of them were collected from lotus fields, two (R-1, R-2) were from rice fields and two (F-1, F-2) were from vegetable fields.

Preparation of microcosms Biodegradation rates were determined in microcosms as follows; 50mls of soil and water mixture were placed into the 68ml serum bottles. Five grams of dry weight soil were used. The soil solution was purged with nitrogen gas for 3 min to make the anaerobic condition. Spiking solutions containing 140mg/l of PCE or 1,100mg/l of TCE in distilled water were prepared and added to the serum bottles to make final amounts of 2.5 to 50μg of PCE or TCE. The bottles were sealed with teflon septa.
Sterile controls were prepared by autoclaving the soils and distilled water for 90 min. All microcosms and sterile controls were allowed to incubate in the dark at 25°C with shaking. Duplicate microcosms were constructed for each conditions.
For the temperature effect on the biodegradation, 10 to 30°C were adopted and for the concentration effect of PCE and TCE, 2.5 to 50μg of substrates were added in microcosms.

Analysis PCE and TCE were periodically determined by gas chromatographic analysis of 0.1 ml headspace sample using a ^{63}Ni electron captured (ECD) or a flame ionization detector with a glass column(3mm by 3m)with 15% Silicon DC200 on 60/80-mesh UniportB. The injection, oven and detector temperature were 300, 120 and 300°C, respectively.
The degradation metabolites were analyzed using a LKB-9000C GC/MS instrument equipped with a PAC500 computer system. The ionization voltage was 20eV and the ion source temperature was 250°C.

RESULTS AND DISCUSSION

Biodegradation of PCE and TCE The degradation curves of PCE and TCE in seven kinds of soils are shown in Fig. 1. PCE and TCE were added 5μg to each serum bottles. The decrease of PCE and TCE in 24 hrs incubation was considered as the adsorption to soil. In the case of PCE, the time of 50% degradation (T_{50}) for L-1, L-2, L-3, R-1, R-2, F-1 and F-2 were 12, 16, 14, 25, 16, 26 and 27 days, respectively. The lotus field soil (L-1) showed the highest degradation ability and 80 % of PCE was degraded in 15 days. The vegetable field soil (F-2)

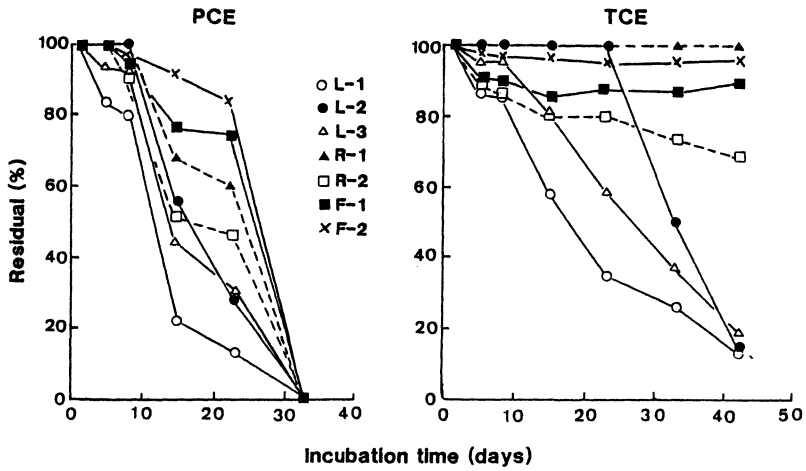

Fig. 1 Biodegradation of PCE and DCE

was the lowest ability to decompose PCE. Only 10 % of PCE was degraded in 15 days. However, PCE was completely degraded in all soils in 33 days. In the case of TCE, the T_{50} values for L-1, L-2 and L-3 were 18, 33 and 36 days, respectively. The T_{50} values for the rice and vegetable field soils were more than 40 days. The high degradation rates were observed in the lotus field soils, and more than 80% of TCE was decomposed at 42 days in L-1, L-2 and L-3 soils. The rice and the vegetable field soils showed the low degradation ability.

The lotus field soils exhibited the high ability to decompose PCE and TCE. In order to clarify the soil parameters on the biodegradation, the soil characteristics were determined. As shown in Table 1, carbon contents of all soil samples were relatively high and between 3.4 and 7.5%. There was no correlation between the carbon content and the biodegradation. No degradation was observed in the sterile control. Therefore, the degradation seemed to be due to the biological reaction.

An unknown peak was detected in the soils amended with PCE. The peak was analyzed by GC-MS and identified as TCE. The reduction amount of PCE and the production of TCE are shown in Fig. 2. The initial amount of PCE was 0.03 μmol in each serum bottle. In accordance with the

Table 1 Characteristics of soil

Items	Lotus field soil			Rice field soil		Vegetable field soil	
	L-1	L-2	L-3	R-1	R-2	F-1	F-2
Sampling place	Tsuchiura city			Tsukuba city		Tsukuba city	
Water content(%)	71	51	63	49	54	46	37
Carbon(%)	5.1	3.4	3.9	3.6	6.5	7.5	4.3
Nitrogen(%)	0.42	0.24	0.39	0.33	0.49	0.49	0.35

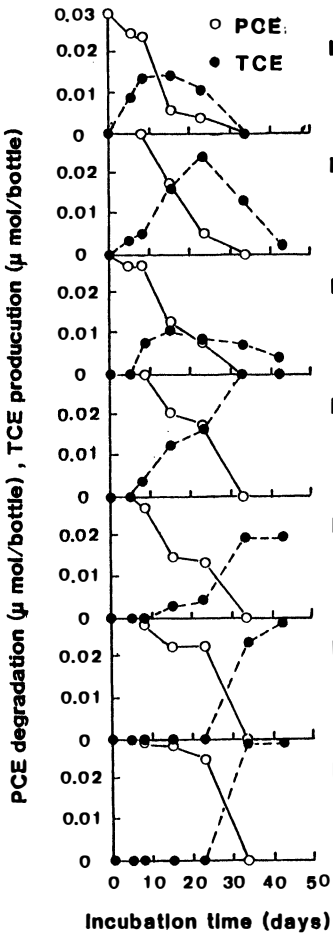

Fig. 2 PCE degradation and TCE production

reduction of PCE, the amount of TCE production increased in all soils. In L-1 lotus field soil, the TCE production reached the maximum of 0.014 μmol in 15 days, then TCE was almost degraded in 33 days. The same patterns for PCE degradation and TCE production were observed in L-2 and L-3 lotus soils.
In the rice and vegetable field soils, TCE was quantitatively transformed to TCE except R-2 soil. The reduction of produced TCE and metabolites of TCE were not observed in 42 days.
It seemed that PCE was more degradable than TCE in soil environment.

Effects of temperature on the PCE and TCE degradation As L-1 soil showed the highest ability to decompose PCE and TCE, the effects of temperature on the PCE and TCE degradation were examined using L-1 soil. The degradation curves of PCE and TCE at various temperature are shown in Fig. 3. The degradation rate of PCE and TCE accelerated with the increase of temperature. The values of T_{50} of PCE and TCE were 7 and 8 days at 30°C, while, 38 and 44 days at 10°C, respectively. The degradation rates of PCE and TCE were not much different in L-1 soil under the low concentration.

Effects of PCE and TCE concentration on the biodegradation Figure 4 shows the effects of PCE and TCE concentration on the biodegradation of PCE and TCE. In the case of TCE, the values of T_{50} for 2.5, 5, 25 and 50μg of TCE addition in the serum bottles were 6, 8, 16 and

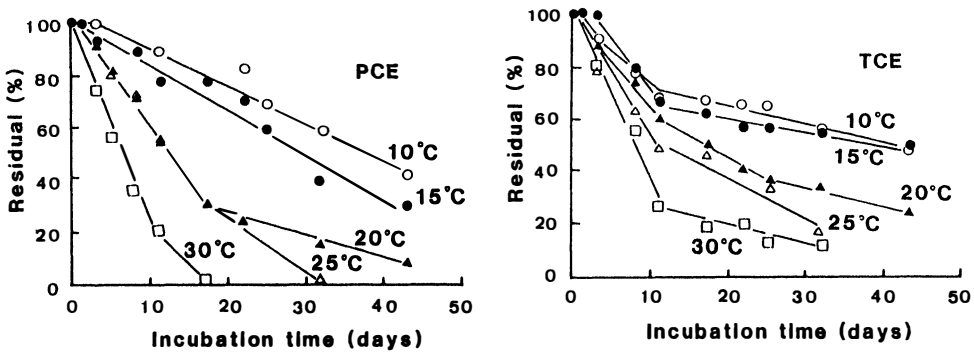

Fig. 3 Effects of temperature on the biodegradation of PCE and TCE

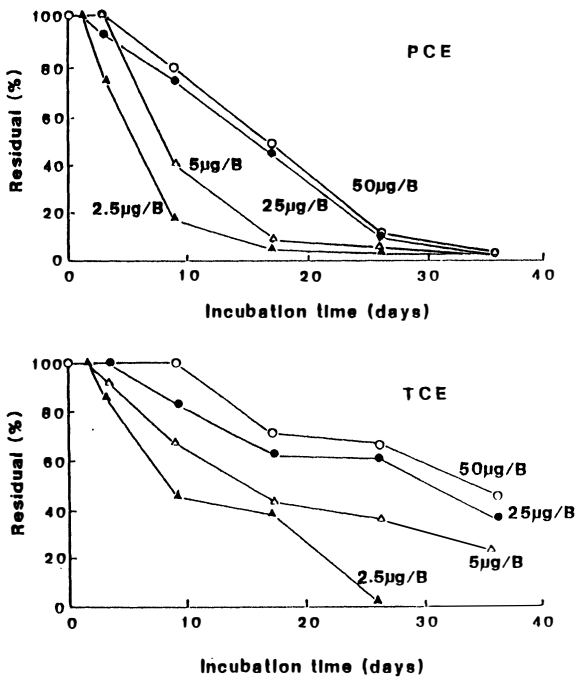

Fig. 4 Effects of PCE and TCE concentration on the biodegradation

17 days, respectively. The values of T_{50} for 2.5, 5, 25 and 50µg of TCE in the serum bottles were 8, 15, 30 and 34 days. T_{50} values decreased with the increase of PCE or TCE concentration. The degradation rate of PCE was higher than that of TCE under the high concentration. The biotransformation of chlorinated volatile organic compounds has been studied by several researchers. However, the degradation rate of these compounds in the soil environment is little known. Robert et al.(1982) reported that biodegradation rate of TCE was considered as first order and the rate constant of TCE was $0.003day^{-1}$ in the groundwater. Barrio-Lage et al.(1986) determined the first-order rate constant of dehalogenation for cis and 1,1- dichloroethylene were $0.853x10^{-4}$ and $3.57x10^{-4}h^{-1}$ in microcosms simulating groundwater. Barrio-Lage et al.(1987) reported the first-order biodegradation rate constant of TCE was very low at $8.7x10^{-4}h^{-1}$ in a natural sediment microcosm. We determined the biodegradation rates of PCE and TCE in various soils. The values of T_{50} for 2.5 and 5µg of PCE were 6 and 8 days in L-1 lotus soil. In these low concentrations, the inhibition of PCE was little observed. Therefore, the PCE degradation rate was calculated as first-order at 5 µg. Six days of T_{50} value is corresponding to a rate constant of $0.115\ day^{-1}$. In the groundwater, the rate constant is usually less than $0.01day^{-1}$. It seemed that the lotus field soil has a very high ability to degrade PCE and TCE.

CONCLUSION

Degradation rates of PCE and TCE were determined in lotus, rice and vegetable field surface soils. The lotus field soil had the highest ability to degrade PCE and TCE. The values of T_{50} in L-1 lotus soil were 8 and 15 days for PCE and TCE under the concentration of 5µg in a 68ml bottle containing 50ml of soil solution. PCE was biologically transformed to TCE in soil. The material balance of PCE depletion and TCE production were determined. The degradation rates of PCE and TCE were significantly influenced by soil source, temperature and substrate concentration.

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