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Degradation of high concentrations of PCE solubilized in SDS and biosurfactant with Fe/Ni bi-metallic particles

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ABSTRACT

A method to rapidly solubilize and degrade perchloroethylene (PCE) was investigated. Enhancing the water solubility of PCE (100 mg/L in water) with an anionic (sodium dodecyl sulfate (SDS)) and a biosurfactant (UH-biosurfactant) were investigated at room temperature in continuously stirred batch reactors. The solubility of PCE in the surfactant solutions increased linearly with increase in surfactant concentrations up to 10 g/L. Of the two surfactants studied, biosurfactant solubilized more PCE per gram of surfactant. To degrade solubilized PCE, bi-metallic iron–nickel (Fe–Ni) particles were used in continuously stirred batch reactors. The bi-metallic particles were synthesized using the solution method and the particles were characterized using the SEM, EDS and XRD. The PCE solubilized in the range of 500 mg/L (five times the water solubility) in both surfactant solutions were degraded at various rates by 200 g/L of bi-metallic Fe–Ni particles. PCE solubilized in the UH-biosurfactant was totally degraded in less than 3 h, which is the highest concentration of PCE degraded in the shortest time compared to the chemical and biological methods used in the past. End products in the solution after the PCE degradation were analyzed to determine the by products and the chloride concentration to ensure complete degradation of PCE. While the degradation kinetics of PCE solubilized in water and SDS solution were linear, PCE solubilized in the UH-biosurfactant was of a higher order.

1. Introduction

Production of solvents began in the United States in the early 20th century, and usage of solvents increased markedly after World War II. Although production has declined, relatively large quantities of solvents continue to be used in industrial, commercial, and domestic applications. Studies on water quality have shown that there is increasing concern over the presence of chlorinated solvents in the aquifers. The chlorinated solvent group is one of the two most frequently detected volatile organic carbon (VOC) groups in the aquifers in the United States and perchloroethylene (PCE) is the second most frequently detected VOC [1]. PCE is used by over 80% of the commercial dry cleaners. PCE degrades slowly under aerobic and anaerobic conditions in the ground. Numerous remediation studies have focused on degrading chlorinated solvents using zero valent metals. Based on the literature view, up to 54 mg/L of perchlorothelene has been degraded using chemical and biological methods (Table 1). PCE (C_2Cl_4) is a colorless, nonflammable, dense non-aqueous liquid (DNAPL) which is widely used in dry cleaning, textile industries, degreasing metal parts and as an ingredient in the manufacture of various chemicals such as chlorofluorocarbons, lubricants and solvents [18]. High levels of PCE when inhaled can cause unconsciousness, headache, sleepiness, confusion and adversely affect the liver and kidney [18]. Microorganisms in soil and groundwater slowly breakdown PCE over time [18]. Because of its lower solubility, immiscibility, relatively slower rates of dissolution and high density it is extremely difficult to remedy PCE [2]. Reviewing the literature indicates that based on the concentration and the method used for degrading PCE, the time taken varied from 100 h to 40 days (Table 1).

Historically PCE contaminated soil was cleaned up by excavating the soil, incinerating it and disposing the ash in a landfill [2]. PCE contaminated groundwater has been treated using pump-and-treat, bioremediation and phytoremediation [18]. The method selected to clean up PCE contamination in soil depends upon factors such as PCE concentration, access to contaminated site, cost of disposal and other site-specific factors [3]. Pump-and-treat is the most common method of treating PCE contamination in groundwater [2,17]. In the pump-and-treat method wells are used to remove contaminated groundwater from the water bearing zone or aquifer, treat it above ground, and then discharge it to a sewage treatment plant or other approved location. Bioremediation uses microor-

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Table 1
Literature review: degradation of PCE using various methods

Reference	PCE concentration	Surfactant/solvent used	Degradation					Remarks
			Process	Material	Amount	Time	Kinetics	
[26]	20 mg/L, lab study	Hexadecyltrimethyl ammoniumbromide (HDTMA-Br)	Chemical	Zero valent iron/solution methods	125 g/L	200 h	First order kinetics	HDTMA-Br was used to modify the surface of iron
[3]	2 mg/L, lab study	Hexadecyltrimethyl ammoniumbromide (HDTMA)	Chemical	Zero valent iron/solution methods	Surfactant modified zeolite/zero valent iron pellets (30 cm × 4.8 cm column)	10 pore volumes required at 1.9 m day^{-1} seepage velocity	Not applicable	PCE reduction rate constants increased as the travel velocity increased
[17]	20 mg/L, lab study	Hexadecyltrimethyl ammoniumbromide (HDTMA)	Chemical	Zero valent iron	125 g/L	100 h	First order kinetics	HDTMA used to modify the surface of iron
[22]	3.3 g/L, field study	None	Chemical	Cement with humic acid	39.2 mM	40 days	Pseudo first order kinetics	Surface reaction appears to control observed PCE degradation kinetics
[27]	54 mg/L, lab study	None	Biological	Microorganisms	Not available	5 days	Not available	Field study
[4]	30 mg/L, lab study	None	Chemical	Zero valent iron	Zero valent iron (5 g in 15 mL vial), pyrite (0.1 g in 15 mL vial)	500 h	Reaction order 1.3	Sorption and reduction of TCE and PCE was analyzed
[5]	9 mg/L, lab study	None	An aerobic mixed culture	Microorganisms	Not available	40 days	Not available	Hydrogen as electron donor
Results	(Mainly lab study) 2–54 mg/L	Surfactants were used to modify the iron surface	Chemical and biological process	Zero valent iron/microorganisms	125–330 g/L of zero valent iron	100 h–40 days to degrade PCE	Reaction order was 1 or 1.3	Chemical and biological methods were used to degrade PCE