

Synergism effect of mixed surfactant solutions in remediation of soil contaminated with PCE

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<Abstract>

The purpose of this research was to evaluate the effect of mixed surfactant solution for removal of perchloroethylene (PCE) in soil. Ten different surfactant solutions were used in column studies. Mixed surfactant solutions (anionic and nonionic) were most effectively worked in the sandy soil for removal of PCE as a result of synergism between the two types of surfactants. The effectiveness of the mixture of surfactants was 35 % greater than that for the anionic or nonionic surfactant alone. The results indicate that mixed surfactant solution leaching is a promising candidate for the remediation of PCE contaminated sandy soil.

Key word : Soil, Remediation, PCE, Surfactant, Synergism

1. Introduction

The contamination of soil and groundwater by PCE is an environmental concern in industrial sites [1, 2]. PCE has been used in the part of industrial and commercial applications such as metal degreasing, cleaning of electronic components and dry cleaning. PCE represents a long-term source of soil and aquifer contamination because PCE possess low solubilities and high interfacial tensions. The high interfacial tensions between PCE and groundwater result in large capillary forces and large displacement entry pressures that resist flushing by water. Currently the common method for remediation of aquifers contaminated with PCE is pump and treat. However, pump and treat method is limited by parameters such as flow rates and the surface area available for mass transfer of PCE [3, 4].

Surfactants are widely used for solubilization/mobilization purposes in agriculture, and industrial area. In recent years, surfactant-enhanced remediation has been employed to remove PCE from contaminated soil and water [5, 6]. Surfactants can be used to vastly increase the solubility of the PCE in water and also lower the interfacial tension at the water-PCE interface [6, 7]. Results from several laboratory studies on the use of surfactants in washing PCE contaminations from soils have shown

that this enhanced washing method has good potential. As a result of investigating many papers, PCE recoveries varied between 68 % and 85 % in these laboratory and field studies [8, 9]. Clearly, more work is needed in this field. The objective of this study was to demonstrate the effect of mixed surfactant solution for removal of PCE in soil.

2. Materials and Methods

2.1. Surfactant selection

Four surfactants of polyoxyethylene (20) sorbitan monostearate (Tween 60), polyoxyethylene (23) lauryl ether (Brij 35), sodium n-dodecyl sulfate (SDS), and diphenyl oxide disulfonates (DOSL) were used in this study. Tween 60 and Brij 35 are nonionic surfactants, which have been noted for their unfavorable tendency to sorption to aquifer solids [10]. Anionic surfactants (SDS, DOSL) are usually chosen for surfactant-based remediation procedures because they showed a good solubilization for hydrophobic organic compounds [5]. Used surfactants are an excellent solubilizer of chlorinated solvents, and their food grade additive status make them attractive for use in environmentally sensitive areas. Also they are rapidly biodegradable by soil and/or aquatic microorganisms. These surfactants were used without further purification. The characteristics of used surfactants are shown in Table 1.

Table 1. The characteristics of used surfactants.

Trade Name	Tween 60	Brij 35	SDS	DOSL
Chemical Name	Polyoxyethylene Sorbitan Monostearate	Polyoxyethylene Lauryl Ether	Sodium N-dodecyl Sulfate	Diphenyl Oxide Disulfonates
Molecular Weight	1310	1198	288	642
CMC (mM)	0.02	0.01	0.81	0.52
Formula	$C_{18}H_{34}O_2C_6H_{10}O_4(CH_2CH_2O)_{20}$	$C_{12}(CH_2CH_2O)_{23}$	$CH_3(CH_2)_{11}SO_3Na$	$C_{16}H_{33}C_{12}H_7O(SO_3Na)_2$
Type	Nonionic	Nonionic	Anionic	Anionic
Company	Yakuri Chemicals, Japan	Kanto Chemicals, Japan	Fisher Scientific, Chicago, IL	Dow Chemical, Midland, MI

2.2. Soil selection

Ottawa quartz sand (US Silica, Ottawa, IL) was chosen as a model porous medium. Its mean grain diameter is 0.45 mm and specific surface area is 0.007 m²/g (US Silica). This sand was washed with deionized water to remove fine materials and air dried prior to use.

2.3. Sequential column leaching tests

Column experiments were performed with a constant temperature. Column experimental procedures were the same as those used in a previous study [1].

A porous ceramic plate beneath the soil prevented loss of soil during leaching.

Approximately 350 g of sandy soil was incrementally packed to a height of 15.4 cm in glass columns (5 cm O.D., 30 cm high). Deionized water was pumped into the bottom of column at a flow rate of 3 ml/min for 3 h to saturate the soil. PCE of 5 ml was injected by syringe into the

middle of the column, which is a method of contamination analogous to a point source of contamination at the field scale. Then 2 % (v/v) or (w/v) aqueous surfactant solutions were pumped into the column at a rate of 3 ml/min. Also, 1:1 volume mixture surfactants were tested. The effluent samples during the surfactant flood were collected in a fraction collector using volumetrically calibrated test tubes. N-hexane was used as a solvent to calibrate a quantitative analysis of gas chromatography. A Tekmar 3000 purge and trap instruments also was used. Helium was used as purging gas at a flow rate of 25 mL/min for 11 min.

3. Results and Conclusions

The effectiveness of the surfactants in removing PCE from soil in column test does not appear to be strongly dependent on whether they are nonionic or anionic based on our experimental results (Fig. 1).

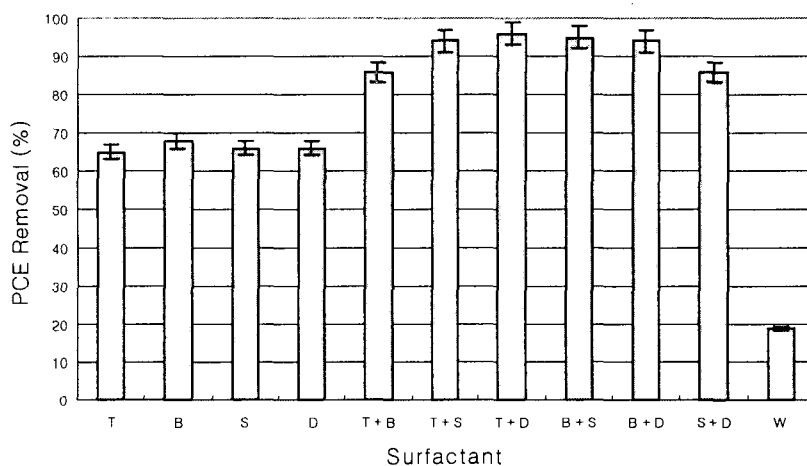


Fig. 1. The effect of mixture surfactant for removal of PCE.

However, a combination of 1 % (v/v) or (w/v) anionic and 1 % (v/v) nonionic surfactant was found to be most effective in removing PCE from soil in this column tests. The effectiveness of the mixture of surfactants was 35 % greater than that for the anionic or nonionic surfactant alone.

The mixture of anionic and nonionic aqueous surfactant solutions substantially enhanced the removal of PCE from soil. This result is comparable to other column studies where similar amounts of different contaminants were removed by surfactant mixtures. American Petroleum Institute [11] showed that a combination of nonionic and anionic surfactants was most effective in displacing gasoline from sand column. They used mixture of 2% Richonate YLA (an anionic alkyl benzene sulfonate) and Hyonic PE90 (a nonionic polyethoxylated nonylphenol). About 90 % of the gasoline was removed by washing with these surfactants. Also, Rickabaugh et al [12] used 2% mixture of nonionic (Triton) and cationic (Emcol) surfactants for removal of chlorinated hydrocarbons from a pesticide-contaminated soil, and found that they removed about 60-65% of the contaminants. In

another study, Eills et al. [13] used a mixture of 2% each of two nonionic surfactants (Adsee 799 and Hyonic NP90) to wash PCB from sand in column experiments. About 70 - 90 % of the PCB was removed by washing with those surfactants. These results showed that effectiveness of surfactants differ depending on the specific organic contaminant. The effectiveness of the surfactants in removing contaminant from soil was dependent on the hydrophilic/hydrophobic structure of the surfactant molecule and CMC (critical micelle concentration). Mixtures of two different surfactants often show a "synergistic" interaction. The mixing of a benzenesulfonate group (anionic) surfactant with a polyoxyethylenated (nonionic) compound shows that increased solubilization occurs when there is interaction between the polyoxyethylene chain and the benzenesulfonate groups. Mixed micelle formation in aqueous solution can be greater than that of the individual components, and explained by nonideal solution theory and molecular environments (pH, temperature, ionic strength of the solution) [14]. Mixtures of an anionic and a nonionic surfactant can also reduce precipitation that may occur with ionic surfactants alone [8]. Attwood and Florence [15] provided a partial explanation as stated: "a cosolubilization effect where one solubilize causes structural alterations in the micelle so enhancing its capacity for another".

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