Bench-Scale Treatability Study

Treatment of Chlorinated Hydrocarbons Using VeruTEK's S-ISCO™ Coelution Technology™

Executive Summary

VeruTEK Technologies, Inc. (VeruTEK) performed laboratory tests on contaminated soil and groundwater. The soil and groundwater is from a chemical solvent manufacturing plant and is contaminated with chlorinated solvents (68 percent Tetrachlorenthene [PCE] and 20 percent Carbon Tetrachloride [CTC]). VeruTEK tested several treatment methods to destroy contaminants. All treatment methods were based on either In Situ Chemical Oxidation (ISCO) or Surfactant-Enhanced In Situ Chemical Oxidation (S-ISCO™). The major finding of the study was that a green remediation technology, S-ISCO™, can be implemented to destroy chlorinated solvents in the subsurface.

Pre-Treatment

Post-Treatment

The columns above were used to test the different treatment methods; dense non-aqueous phase liquid (DNAPL) was colored with red dye and placed in the soil column to illustrate the presence of contaminants in the column similarly to how they are found in the subsurface. The column that used the S-ISCO™ technology achieved nearly complete removal of contaminants in less than 5-days time. After 5 days, the ISCO column still shows that a majority of the DNAPL remains.

Introduction & Site Overview

VeruTEK conducted tests on soil and groundwater contaminated with chlorinated solvents from an industrial facility. The contaminants leaked into the soil from underground storage tanks located at the facility. Historically, chlorinated hydrocarbons have been used in the dry cleaning process, and as a degreaser in the automobile industry. Chlorinated solvents are carcinogenic and their removal from the ground is essential to the human health and the environment.

Soil samples collected from the facility showed that 99% of the contamination was composed of five compounds: tetrachloroethene (accounting for 60% of total contamination), carbon tetrachloride, hexachlorobutadiene, hexachloroethane, and hexachlorobenzene.

ISCO & S-ISCO™ Background

Traditional In-Situ Chemical Oxidation (ISCO) processes involve the injection of oxidants (i.e. sodium persulfate, permanganate, or hydrogen peroxide) into contaminated soils. Oxidants then react with and break down contaminants into harmless compounds. However, ISCO generally fails to treat non-aqueous phase liquids (NAPLs), such as chlorinated solvents, because these chemicals do not dissolve readily in groundwater. NAPLs will form a separate liquid that does not mix with groundwater. Only a small fraction dissolves in groundwater, but this fraction is enough to make the affected groundwater unsafe for use. ISCO chemical reactions occur predominantly in groundwater and do not significantly impact contaminants as a NAPL or bound to soil. This is demonstrated by a study in Colorado in which 15 of 20 sites implementing ISCO remediation plans failed to remedy present soil contaminants[1].

While ISCO is capable of treating contaminated groundwater, over time the contamination will return because the NAPL is still present. This NAPL provides a constant source of contamination to the groundwater. However, NAPLs are often more dense than water and will sink into the water table, making them difficult to treat directly. They also dissolve slowly in groundwater, making it impractical to simply pump and treat the groundwater.

Surfactant-enhanced In-Situ Chemical Oxidation (S-ISCO™) is a new, field verified Coelution Technology™ capable of reducing NAPL levels in soil as well as the flux of groundwater contaminants. VeruTEK's patent-pending S-ISCO™ technology uses VeruSOL™, a biodegradable, U.S. FDA Generally Recognized As Safe (GRAS) mixture of citrus-based cosolvents and plant oil-based surfactants, to greatly improve dissolution of NAPL compounds into groundwater. This effectively destroys the NAPL portion of a contaminated site by greatly accelerating the rate at which it dissolves into groundwater. Once dissolved the contamination can then be targeted and destroyed by conventional ISCO oxidants, such as persulfate.

Testing Procedures

Soil, groundwater, and DNAPL samples were received by VeruTEK and were analyzed to determine composition and presence of various contaminants. Additional tests were conducted prior to the column experiments to determine the optimal experimental conditions.

Preliminary tests included contaminant solubilization enhancement, and destruction experiments. Various doses of VeruSOL™ and activated persulfate were tested to determine the optimal experimental conditions to be used during the column experiments. Results from the experiments revealed that even with a low concentration of VeruSOL™ nearly all of the DNAPL was dissolved within 72 hrs. With the addition of activated persulfate ~93% of the solubilized contaminants were destroyed within the 14-day experiment.

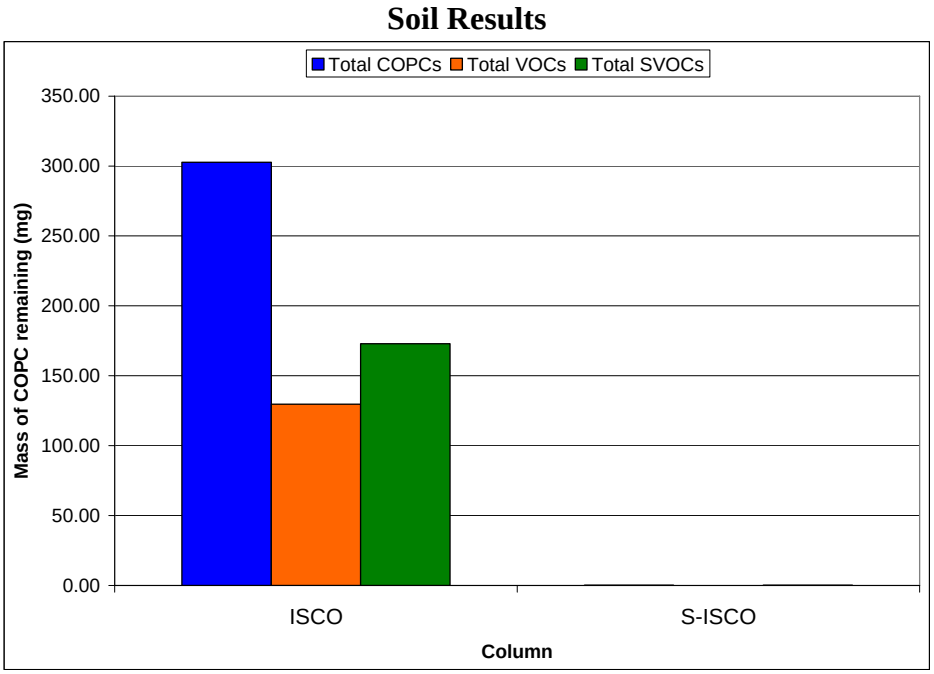
Once all preparations and preliminary tests were completed soil samples were packed into columns like those seen in pictures previously. Chlorinated solvents contamination (mixed with red dye for ease of identification) was injected into each column to simulate DNAPL as it would occur in the soil at the facility. The columns were then subjected to ISCO and S-ISCO™ treatments.

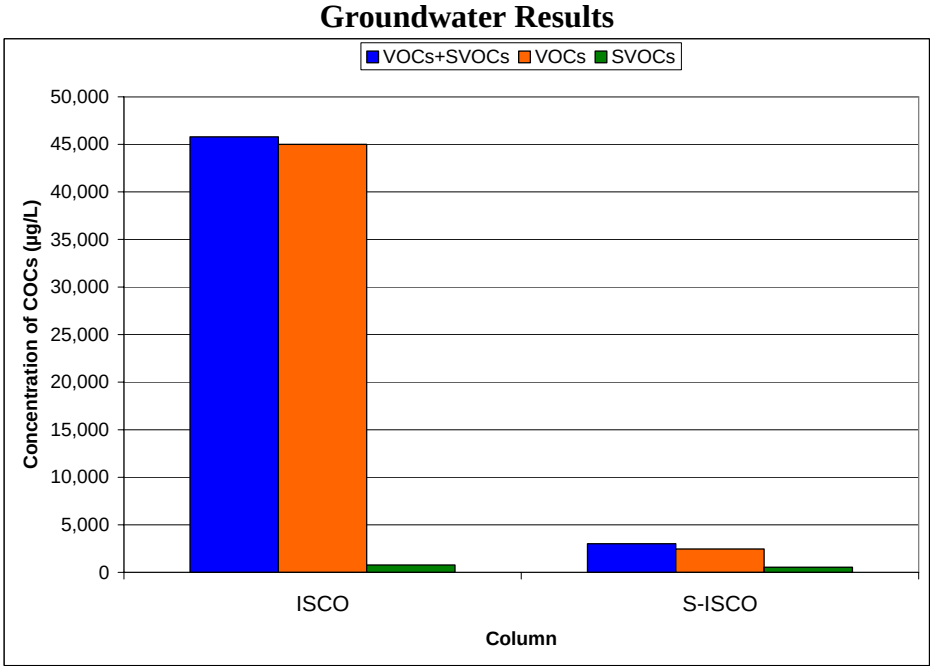
Treatment in the two columns continued for 14 days; water leaving the column was tested for a variety of parameters, including contaminant concentrations (indicates the dissolution of contaminants) and chlorine ions (indicates the destruction of contaminants).

[1] The Colorado Department of Labor and Employment, Division of Oil and Public Safety. (2007) *Petroleum Hydrocarbon Remediation by In-situ Chemical Oxidation at Colorado Sites*, June 2007.

RESULTS

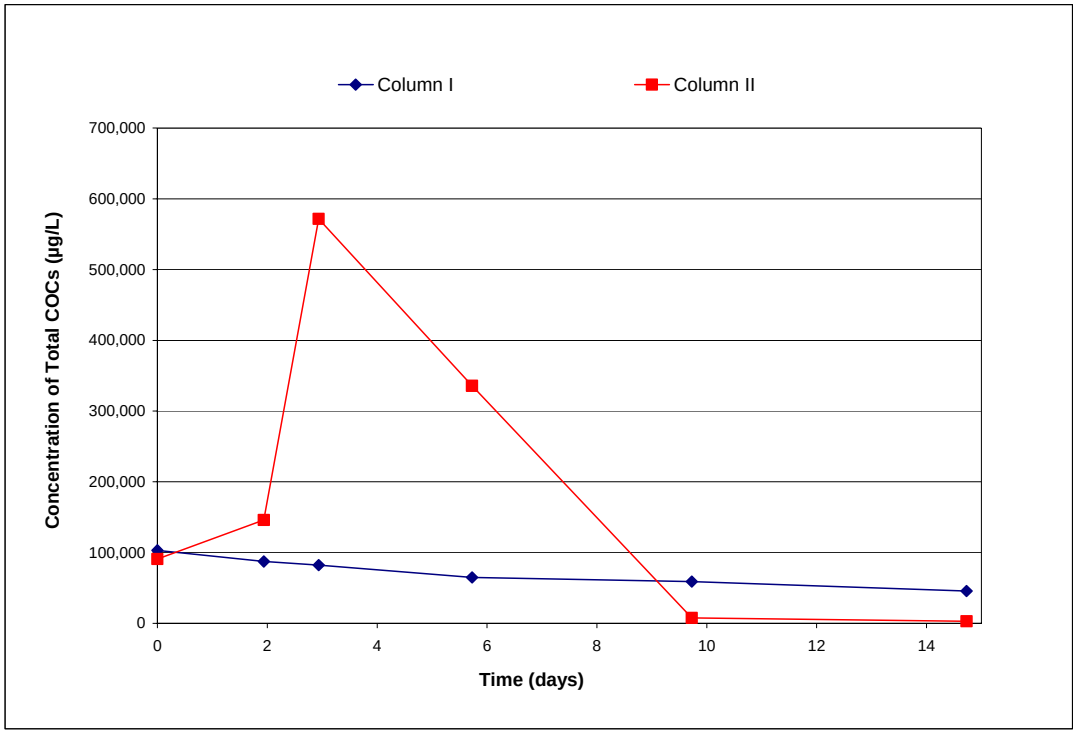
Once the column tests were complete, the soil in the columns was sampled for contamination. Also, the groundwater leaving the columns was sampled for contamination.





As shown in these graphs the S-ISCO™ technology achieved complete or near-complete destruction of all contaminants. The ISCO column failed to destroy a significant amount of the contamination.

The success of S-ISCO™ during this test is further demonstrated by the plot of contaminant concentration in groundwater over time during testing:



Concentrations of Groundwater Contaminants Leaving the Column

The S-ISCO™ technology demonstrates an increase in dissolved contamination levels, to nearly six times the level seen in the ISCO column. Dissolving these normally insoluble contaminants into the groundwater is the key to achieving long-term, complete soil remediation. After only 10 days, the S-ISCO™ technology has dissolved/destroyed all DNAPL contamination that was present in the column. As shown in the figure on Page 1, the ISCO column after treatment indicates that a significant presence of the DNAPL remains. This is confirmed by the resultant groundwater concentrations measured from that column for the duration of the tests, as graphed above.

Conclusions

- The S-ISCO™ technology can be optimized to safely and cost-effectively destroy chlorinated solvent contamination.
- Traditional ISCO methods are hampered by kinetic and transport constraints such that complete or near-complete destruction of contamination is not possible, as demonstrated in the soil column tests.
- The soil column experiments demonstrated that the S-ISCO™ technology, controls the rate of dissolution and destruction such that treatment of chlorinated solvent DNAPL and sorbed residual contamination can be achieved in field applications.
- VeruTEK is fully capable of optimizing the S-ISCO™ process to provide complete or near-complete destruction of chlorinated solvent contamination.