Overview

This comprehensive report summarizes the results of work on the *"Permanganate Treatment of DNAPLs in Reactive Barriers and Source Zones".* The study was sponsored by the Department of Energy as part of their Environmental Management Science Program (DE-FG07-96ER14735). The results presented here represent the collective efforts of a team from The Ohio State University and Duke Engineering & Services. Researchers at the Ohio State University were primarily responsible for the experimental work, while Dr. H. Zhang at Duke Engineering & Services undertook the numerical modeling. Besides contributing to the research, Dr. Y. Seol played a major role in the preparation of the report itself.

In large part, the chapters in this report represent contributions to journal articles and conference proceedings, some of which are in press and the remainders of which are in submittal. Beyond the written contributions our group also has been active in presenting talks and poster sessions at various DOE workshops and program reviews as well as professional societies like the American Geophysical Union and the Geological Society of America. We have made the results of these studies available to other researchers and consultants interested in oxidation schemes for DNAPL clean ups.

The research group contributing to this report consists of the following individuals.

Dr. Franklin W. Schwartz joined The Ohio State University in 1988 as the Ohio Eminent Scholar in Hydrogeology. He was formerly a Professor of Geology at the University of Alberta. Frank is the author of more than 110 publications and is known internationally for his work on field and theoretical aspects of mass transport, contaminant hydrogeology, and ground-water geochemistry. He is co-author of the textbook *Physical and Chemical Hydrogeology,* which is now in its second edition. He is the recipient of numerous awards including the prestigious O.E. Meinzer Award in 1984, the Excellence in Science and Engineering Award in 1991, and the King Hubbert Science Award in 1997. He was elected as a Fellow of the American Geophysical Union in 1992.

Dr. Hubao Zhang, a co-PI on this project, was graduated from The Ohio State University in 1995 and joined Duke Engineering & Services in Albuquerque, New Mexico. Dr. Zhang was a recipient of a Presidential Fellowship at Ohio State. He is a specialist in the development and applications of flow and transport models to problems of radionuclide migration and site remediation. He has published 10 papers related ground-water flow and transport modeling and in addition to this work on solvent oxidation has been involved with suitability assessments of Yucca Mountain.

Dr. Yonkoo Seol joined this research project as a Post-Doctoral Research Associate in late 1998. He was graduated from Purdue University in 1998 in Soil Organic Chemistry. Dr. Seol is an aquatic chemist and hydrogeologist with an interest in the behavior of man-made contaminants in natural systems. In this project, his work has been concerned with the development of chemical approaches to enhance the oxidation reactions with chlorinated solvents. Dr. Seol has one paper in press related to this study and two submitted.

Dr. Min-Ho Koo worked as a Postdoctoral Research Associate on this project for about 10 months. Dr. Koo received his Ph.D. degree from Purdue University. His work here was to explore whether the rates of oxidation reactions could be enhanced in co-solvent solutions. Aspects of this work remain to be completed, with preliminary results looking promising at least for some alcohols. Dr. Koo

joined Konju National University in Korea as an assistant professor of hydrogeology in 1997.

Dr. Y. Eugene Yan undertook fundamental scientific studies on the rates and reaction pathways involved with the oxidation of chlorinated compounds with permanganate as part of his Ph.D. dissertation at The Ohio State University. He has published two papers on this topic and a third is in submittal. Following his graduation in 1998, Dr. Yan joined Argonne National Laboratory, where he is working on problems of contamination due to agricultural activities.

X. David Li is a Ph.D. student at The Ohio State University. His dissertation is concerned with the examining the autocatalytic reaction kinetics, and the limitations of permanganate-based schemes for remediation. More specifically, he is concerned with potential releases of heavy metals in the oxidation process and the impact of MnO_2 on flooding efficiency. He has one paper in submission and expects to graduate in 2001.

Sangsuk Lee is a Ph.D. Student at The Ohio State University. He is studying on impacts of urban storm runoff on surface water quality in an urban watershed. His research is also focused on the application of new semiconductor devices to environmental monitoring. Mr. Lee expects to graduate in 2001.

Yao-Chuen Fang is a Ph.D. student at The Ohio State University. He is working on techniques to monitor permanganate schemes in field settings and flooding efficiencies in large-scale three-dimensional systems. Mr. Fang expects to graduate in two years.

Published Contributions Related to the DOE-Sponsored Work

Yan, Y.E. and F.W. Schwartz, 1998. Oxidation of chlorinated solvents by permanganate. *Physical, Chemical and Thermal Technologies*, Battelle Press, Columbus, p. 403-408.

Yan, Y.E. and F.W. Schwartz, 1999. Oxidative degradation and kinetics of chlorinated ethylenes by potassium permanganate. *Journal of Contaminant Hydrology*, 37(3-4), 343-365 .

Yan, Y.E. and F.W. Schwartz, 2000, Kinetics and mechanisms for TCE oxidation by permanganate. in press, *Environmental Science and Technology*.

Seol, Y. and F.W. Schwartz, 2000. Phase-transfer-catalysis applied to the oxidation of nonaqueous phase trichloroethylene by potassium permanganate, in press, *Journal of Contaminant Hydrology*.

Seol Y. and F.W. Schwartz, 2000. Oxidation of DNAPL mixtures using potassium permanganate with a phase-transfer-catalyst; kinetic results from a digital photographic monitoring method, submitted to *Ground Water Monitoring and Remediation*.

Seol, Y. and F.W. Schwartz, 2000. Phase-transfer-catalysis on the oxidation of trichloroethylene by permanganate. Proceeding in press, The Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds. May 22-25, 2000, Monterey, CA

Zhang, H. and F.W. Schwartz, 2000. Simulating the *in situ* oxidative treatment of chlorinated ethylenes by potassium permanganate. In revision, *Water Resources Research*.

Zhang, H. and F.W. Schwartz, 2000. Simulation of oxidative treatment of chlorinated compounds by permanganate. Proceeding in press, The Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds. May 22-25, 2000, Monterey, CA

Li, X. and F.W. Schwartz, 2000. Efficiency problems related to permanganate oxidation schemes. Proceeding in press, The Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds. May 22-25, 2000, Monterey, CA

Ibaraki, M. and F.W. Schwartz, 2000. On source-zone flooding for treating DNAPL sites. Proceeding in press, The Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds. May 22-25, 2000, Monterey, CA

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