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Evaluation of In Situ Bioremediation of 1,4-Dioxane by Metabolic and Cometabolic Bacteria by Using a Contaminant Transport Model

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Background/Objectives. A wide variety of microbes are capable of aerobically biodegrading 1,4-dioxane as a sole carbon and energy source. Aerobic cometabolism also occurs by several types of microbes that grow on a primary substrate such as methane or propane. Bioaugmentation with microbes that metabolize 1,4-dioxane has several advantages, including a reduced likelihood of clogging the aquifer, lower oxygen demand, and no need to provide a primary substrate. However, the concentration of 1,4-dioxane in most plumes is below 1,000 µg/L, which may not support metabolic biodegradation at a sufficiently high rate. The objective of this study was to evaluate the in situ conditions that favor cometabolic or metabolic bioremediation of 1,4-dioxane.

Approach/Activities. A contaminant transport model was developed using COMSOL to simulate metabolic and cometabolic bioremediation of 1,4-dioxane via bioaugmentation and biosparging. Propane was selected as the growth substrate to support cometabolism. The model incorporates multi-substrate Monod kinetics and coinhibition effects. Biodegradation was coupled to a steady-state air sparging model for an aquifer in which oxygen and propane were continuously injected to support bioaugmentation with the propanotroph *Rhodococcus ruber* ENV425. For metabolic degradation, the model simulated bioaugmentation with *Pseudonocardia dioxanivorans* CB1190 and sparging with air alone. Kinetic parameters were determined in a prior laboratory study using both bioaugmentation cultures. The model was calibrated with monitoring well data for 1,4-dioxane and propane from a pilot study at Vandenberg Air Force Base (VAFB). Sensitivity analysis was performed for several model parameters. The metrics used to compare metabolic and cometabolic bioremediation included the time to achieve an average 1,4-dioxane concentration of 1 µg/L and the percentage of biodegradation that occurred after 10 years.

Results/Lessons Learned. The model was very sensitive to parameters such as the biomass decay coefficient. A value 10 times lower than what was measured in suspended growth cultures was needed in order to calibrate the model to field data from VAFB. It was also necessary to reduce the maximum specific 1,4-dioxane biodegradation rate by 50%; this is likely a consequence of measuring the rate in the laboratory in the absence of chlorinated ethenes and ethanes, while they were present at VAFB and are known to inhibit aerobic biodegradation of 1,4-dioxane. The model was also sensitive to variations in the biomass dispersion coefficient and intrinsic permeability. Simulation results indicated that bioremediation of 1,4-dioxane using cometabolism was more effective when the initial concentration was below 10 mg/L; the time to achieve 1 µg/L was at least one order of magnitude higher for the metabolic culture. The rate of biomass injection (8.4E-8 to 8.4E-5 kg COD m^{-2} s^{-1}) had a significantly greater impact on the time to reach 1 µg/L with the metabolic culture, since the primary substrate for cometabolism (propane) was provided in excess. The oxygen injection rate (2.0E-6 to 2.0E-3 kg COD m^{-2} s^{-1}) had a greater impact on the percentage of biodegradation for the metabolic culture. Increasing the propane injection rate (3.54E-7 to 3.54E-4 kg COD m^{-2} s^{-1}) significantly reduced remediation times for cometabolism, although this effect plateaued at the higher rates. Although the model used in this study was calibrated to a specific site, it provides a framework for comparing the performance of metabolic and cometabolic bioremediation of 1,4-dioxane at other sites with different in situ conditions.