Field Demonstration of In Situ Bioremediation of 1,4-Dioxane: A Push-Pull Testing Investigation

Yue Li (byli@gsienv.com) and David T. Adamson (GSI Environmental Inc., Houston, TX, USA)
Jacques Mathieu (Sentinel Environmental, Houston, TX)
Anthony S. Danko (NAVFAC EXWC, Port Hueneme, CA, USA)
Clayton S. Sorensen (Balance Hydrologics, Inc., Berkeley, CA)

Background/Objectives. 1,4-Dioxane is found widely in groundwater impacted by chlorinated VOCs (CVOCs) but is challenging to treat using many common remedial approaches, including biodegradation with native microbes. In addition, its high solubility and low sorption characteristics can lead to the development of extended, dilute 1,4-dioxane plumes in some cases. This project funded by the U.S. Navy's NESDI program aimed to evaluate the in situ biotreatability of 1,4-dioxane using a variety of approaches, with a specific goal of establishing the viability of several different metabolic 1,4-dioxane degrading cultures and an estimate of the relative in situ biodegradation rates.

Approach/Activities. The demonstration was performed at a former waste disposal area in a facility located on the west coast of the U.S. The targeted area was an unconsolidated, permeable sandy aquifer where a groundwater plume of 1,4-dioxane and CVOCs is present below the water table at approximately 28 ft below ground surface. Three treatment approaches were evaluated during the pilot-scale, in situ demonstration using a series of push-pull tests (PPTs): (1) monitored natural attenuation; (2) biostimulation, and (3) bioaugmentation. For the bioaugmentation test, the focus was on developing and scaling up two cultures capable of metabolic degradation of 1,4-dioxane in lab settings, namely CB1190 and PH-06, and then examining the effectiveness of these cultures in field conditions via the push-pull tests. A passive aeration approach based on Waterloo emitters^{TM} was used to minimize the footprint of the field demonstration and also reduce costs compared to large-scale aeration systems.

Results/Lessons Learned. The results showed that degradation of 1,4-dioxane by indigenous microbes was limited at this site: the low degradation rates observed in both the natural attenuation test (approximately zero), and the biostimulation test (-0.0006 hr^{-1}) where the subsurface was aerated to an average DO level of 19 mg/L. The lack of biomarkers from qPCR analysis of sample collected after these two tests further explained the limited biotreatability with native microbes, despite the increased availability of DO during the biostimulation test. In the bioaugmentation tests where both passive aeration and bacteria cultures were included, only CB1190 resulted in a significant concentration reduction of 1,4-dioxane (74%) with the overall degradation rate coefficient obtained for 1,4-dioxane of -0.00725 hr^{-1}. The CB1190 bioaugmentation was also more successful based on biomarker (thmA) and total population (16S) qPCR testing. However, the data also suggested that a hydraulic barrier had formed around wells that hindered the mass transfer of not only 1,4-dioxane to the well screen but also the nonreactive tracer bromide. A hypothesis was proposed, involving the formation of CB1190 biofilms and extracellular polymeric substances (EPS) and a three-step attenuation process including short-term aqueous biodegradation, adsorption, and heterogeneous degradation. Significant declines in most CVOCs were observed during the bioaugmentation with CB1190 and especially PH-06. The concentration reductions in CVOCs observed with PH-06 were attributed to volatilization (which was observed in other tests) and also possible biodegradation by the added cultures. The field demonstration provided insights on in situ

treatment of 1,4-dioxane and highlighted that bioaugmentation may be warranted at many sites but requires effective amendment delivery with significant engineering challenges.