Safe, Effective Steam Remediation: Constraints on Removal Mechanisms and Optimum Operational Strategy

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Thermal treatment using steam has proven to be an effective remediation method. An ongoing concern is the potential for mobilization and potential downward migration of large volumes of DNAPL. Finite element models of steam injection using simple homogeneous lithology predict development of a separate-phase DNAPL bank ahead of the steam front. If sufficient connected DNAPL develops along an underlying aquitard, the phase pressure can eventually overcome capillary forces, allowing the DNAPL to move downward into or through the "floor" of the steamed interval. Using a multiphase, nonisothermal unsaturated flow and transport code (NUFT), we have been performing engineering calculations to examine the behavior of all phases in both homogeneous and heterogeneous systems undergoing steam remediation. These analyses consider the effects of heterogeneity at the site, a factor that has been shown to be important to contaminant flow and transport. Using realistic heterogeneity for alluvial systems, TCE accumulations do not form due to the separation of the steam front into a number of small, advancing fronts along slightly more permeable strata. One approach proposed to mitigate downward DNAPL migration is co-injection of air to reduce steam zone temperature and provide a "carrier" gas to remove volatilized DNAPL. However, the injection of large volumes of air can present other problems regarding control of the vapor phase transport of contaminants in the relatively uncontrollable gravity-driven flow of the gas phase. When we simulate co-injection of air with the steam, the air flow tends to bypass DNAPL accumulations because of the pressure generated by vaporization of DNAPL. Thus large amounts of air move through the system without remediating the DNAPL, and creating the potential for dispersal of contaminant if vacuum collection wells are not perfectly placed.