Fundamentals of Steam-Enhanced Remediation and Field Applications

Lloyd Stewart (Bo@Praxis-Enviro.com) (Praxis Environmental Technologies, Inc., Burlingame, CA, USA)

Background/Objectives. Steam injection is an enhancement to the long established processes of contaminant extraction and biological degradation. Yet, in field practice it has been generally viewed as a standalone technology best left to a handful of experts and limited to the single concept of “capital costs are high, therefore steam the hell out of it.” The prevailing focus is on putting steam into the ground with the belief that given a sufficient but practical quantity of energy, put in the right places, the site can attain final remedial action objectives rapidly. This outcome is rarely, if ever, achieved because steam enhanced remediation is subject to the same hydrogeological and mass transfer constraints faced by the unenhanced process. Contaminant properties and site heterogeneity are not adequately considered during evaluation and design and the remedial goals for the enhancement are unrealistic. With field examples, this talk will describe how steam injection can be applied in different ways to dramatically enhance a variety of remedial processes in a cost effective manner with a basic understanding of the processes involved.

Approach/Activities. Straightforward design of steam enhancements consider mass balances on the contaminant and water, an energy balance, and a few concepts regarding the remedial process being enhanced (e.g., NAPL recovery, biodegradation, mass transfer in heterogeneous soils). The design basis for a steam injection system is based on four interrelated factors: the contaminant and hydrogeology, the remedial process, the remedial action objectives/timeframe, and the incremental cost. For instance, application to a dissolved chlorinated compound in highly heterogeneous, saturated soils should be substantially different from hydrocarbon NAPL recovery at the water table. Volatilizing a chlorinated compound from a silt/clay lens for extraction may prefer dry (low liquid content) steam. Whereas enhancing NAPL recovery with a wet steam (high liquid to vapor content) is more appropriate to avoid clogging pore space with mobilized NAPL that is ultimately bypassed. Enhancing biological degradation may have differing target temperatures and heating rates for aerobic and anaerobic process (e.g., achieved with co-air injection to adjust temperature). A practical remedial goal for the enhancement such as reducing the timeframe for MNA would promote more cleanup. Incremental costs can be minimized by maintaining temperatures acceptable to existing infrastructure (e.g., co-air/steam injection) and existing treatment systems (e.g., sequencing or phasing contaminant loading increases with a steaming schedule) while avoiding specialized equipment (e.g., extraction pumps). Straightforward engineering equations describing rates and balances will be briefly described for adjusting injection conditions and rates of contaminant mobilization or degradation as well as for estimating duration of treatment.

Results/Lessons Learned. The approach and underlying concepts will be illustrated with results from three successful applications. These brief case studies will include: (1) steam injection applied to TCE DNAPL below the water table; (2) co-air/steam injection to enhance volatilization and both aerobic and anaerobic degradation of kerosene; and (3) wet steam injection for pooled LNAPL mobilization and recovery. The talk will also touch on a few pitfall field examples and their causes including (1) dry steam injection to mobilize a heavy hydrocarbon NAPL that yet yielded distillation products shutting down the project upon condensation; (2) inadequate extraction (both mass and energy) to match the steam injection

resulting in loss of containment and adverse contaminant migration; and (3) insufficient energy introduction associated with hot water injection to mobilize NAPL for recovery.