State of the Practice: Heat-Enhanced In Situ Remediation

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Background/Objectives. Remedies for complex sites containing nonaqueous phase liquids (NAPLs) often require multi-technology remedies to achieve stringent cleanup criteria. Aggressive treatments, such as in situ thermal technology, can remove large quantities of NAPL, but are expensive and energy-intensive. Other in situ treatments, including abiotic and biotic degradation, can be applied at NAPL sites cost-effectively but are limited by long remedial timeframes due to the slow NAPL mass transfer (i.e., dissolution) rates to groundwater, where chemicals are available for degradation reaction(s). Combined approaches using heating with in situ technologies can provide the benefits of both heating and in situ treatments to achieve remedial goals more efficiently. An overview of heat-enhanced remedial approaches will be provided along with state of the practice techniques and design considerations.

Approach/Activities.
Using heat to enhance in situ remediation takes advantage of several technology synergies to treat contaminant plumes more cost effectively than can be achieved with heating alone or in situ technologies at ambient temperatures (e.g., bioremediation, hydrolysis or zero valent iron). A key to success for combining technologies is to define the “sweet spot” where the cost of heating is more than offset by the increase in treatment efficiency for the in situ remediation technology. The major limitation to applying in situ treatments at NAPL sites is that contaminant mass destruction only occurs in the aqueous phase, and therefore is limited by the relatively slow dissolution rate of many NAPLs. Heating can significantly improve both mass transfer and reaction rates through the following mechanisms:

- Dissolution rates increase with temperature as solubility increases and viscosity, interfacial tension and density decline
- Desorption rates increase with temperature
- Volatilization rates increase with temperature
- Degradation reaction rates increase with temperature which can maximize the concentration gradient between the DNAPL and water interface generating more soluble degradation daughter products

Results/Lessons Learned. Successful heat-enhanced in situ remedial designs have included available heating technologies (i.e., electrical resistance heating, thermal conduction heating and steam injection) and in situ biotic and abiotic treatment technologies in various design configurations. The technologies have been applied sequentially, in parallel and concurrently to treat chlorinated solvents, petroleum hydrocarbons and polyaromatic hydrocarbons. Case studies will be presented that highlight these different applications and the lessons learned from the technology implementation and long-term performance evaluation. Overall, the application of heat can increase treatment rates by orders of magnitude thereby reducing the remedial timeframe while in situ technologies degrade contaminants in place resulting in less infrastructure and cost.