On thermally enhanced remediation of DNAPL contaminated sites

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Introduction

Since the 1980’s, the remediation of contaminated soils containing non aqueous phase liquids (DNAPLs) form a major task within the field of environmental sciences. Soil remediation in its early stages was mainly focused on the removal of contaminated soil by excavation, and subsequent transport to an off-site location where the soil was either treated or dumped. Excavation was often supplemented with groundwater extraction and above ground treatment, so-called pump and treat, and soil vapour extraction to remove residual contaminants from the water and gaseous phase. Later natural attenuation came in focus using the auto-recovery capacity of the soil for the removal of dissolved organic contaminants. However, often (semi-) volatile organic contaminants present as a DNAPL in the subsurface were not, or only partly, removed. DNAPLs are in general located on and partly in lower permeable layers, lenses or strata within a more permeable matrix such as sand, and can permeate the subsurface to great depths. Often DNAPLs contain the main fraction of the contaminants with often >99% of the total contaminant mass. Release of contaminants from these DNAPLs to the water and vapour phase under ambient conditions is slow and depending on the diffusion and dispersion rates. In general the solubility of the compounds within the DNAPLs is relatively low, about 1 g/L or less. This slow release and the large contaminant mass hampers the fast and complete removal of the contaminants, resulting in vast plumes of contaminated groundwater that can persist for decades.

Due to the depth of the DNAPLs and the large fraction of the mass located in the DNAPLs, direct in-situ treatment of the DNAPLs is the only way to achieve a complete removal of these types of contamination. Thermally enhanced extraction technologies are capable of mobilising and removing the contaminants from the subsurface. The applied heat leads to increased diffusion rates, higher aqueous solubilities, and faster vaporisation. Heat mobilises the contaminants often orders of magnitude faster than possible under ambient conditions. However, the mobilised contaminants from the DNAPL need to be extracted from the water and vapour phase. Application of thermal enhanced remediation techniques without a proper extraction system can cause severe problems due to the uncontrolled migration of contaminants.

Thermal enhanced techniques

Three basic heating technologies are available: electromagnetic heating, fluid enhanced heating, and conductive heating. Of these three, electrical heating and fluid enhanced heating are applied most commonly. Conductive heating has gained some ground in recent years as techniques such as Six Phase Heating and electrical resistive heating have been introduced. Fluid heating is most often done using steam injection and sometimes via hot water injection. Most of these techniques originate from the oil industry to enhance oil recovery from the source rock and have been successfully used over the last decades.
Already in the late 1980's, first tests were conducted on the application of thermally enhanced remediation of sites contaminated with organic compounds present in DNAPLs. However, thermally enhance remediation did not become a common remedial strategy as unsuccessful application and relative high costs hampered large-scale application. Currently, both steam injection and electromagnetic heating are applied on a more routine basis in the USA. Within Europe thermally enhance remediation is only rarely applied. To our knowledge steam heating and electromagnetic heating have been applied at a limited number of sites in Germany, Denmark, Czech Republic, and The Netherlands.

**Case study**

Hot water flushing is derived from steam injection is only applied in recent years at a limited scale, due to its low heat capacity as compared to steam injection. There are, however, exceptions where hot water is preferred over steam. On a site in the UK, the nature of the contaminant, carbon disulphide, makes safe application of steam injection to extract a number of CS2 DNAPLs impossible. CS2 is a highly explosive compound with an auto ignition temperature of 102°C. However, auto combustion has been found at temperatures as low as 80°C. The CS2 DNAPLs are present at approx. 5 m below ground level and have accumulated in a gravel/course sandy layer on top of a low permeable clay layer. At the site, the removal of the DNAPL is urgently needed. As the boiling temperature of CS2 is approx. 46°C, in-situ volatilisation of the DNAPL is possible with hot water flushing. Injection of hot water, at 75°C, causes the DNAPL to dissolve and vaporise. The mobilised contaminants are subsequently removed with soil vapour extraction and groundwater extraction systems. During operations, the removal efficiency can be controlled by observation of the temperatures in the subsurface. Currently, a 2D box experiment on hot water flushing to remove the CS2 DNAPL is conducted by the University of Stuttgart, Germany. Additionally, a field scale pilot is developed. Implementation of the pilot is projected at the beginning of 2003, with a full scale application planned for autumn 2003. Preliminary results and design will be presented and discussed in comparison with other applied thermal enhanced remediation of DNAPLs.