The potential for reductive dechlorination after thermal treatment of TCE-contaminated aquifers - DTU Orbit (24/08/2019)

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This thesis presents the results of an investigation of the potential for reductive dechlorination after thermal treatment of TCE-contaminated aquifers' with focus on reductive dechlorination of trichloroethene (TCE) after electrical resistance heating (ERH) and includes seven journal papers and a technical note describing the work undertaken for this PhD project.

Chlorinated ethenes as perchloroethene (PCE) and TCE were useful to industry because of their physico-chemical properties. PCE is most commonly known for its use in the drycleaning industry, whereas TCE was previously used as a degreasing solvent. Due to their widespread use, chlorinated ethenes are commonly detected groundwater contaminants. They are among the most commonly found groundwater pollutants and are detected at approximately 80% of all superfund sites in the USA. Remediation of these compounds from polluted soil and groundwater is a challenging task because of various factors including the pollutants complex spreading pattern in the subsurface, their low aqueous solubility that exceeds the drinking water limits, diffusion from free-phase product, and their higher density than water. Due to this, various innovative remediation technologies have been developed and applied to reach regulatory goals.

Thermally enhanced remediation technologies overcome many factors affecting the removal of DNAPL mass. However, these technologies are often expensive, and a coupling of more than one technology may reduce the overall cost and time.

Chlorinated ethenes can also be biologically degraded, which makes them interesting from a remediation perspective. In nature, higher chlorinated ethenes as PCE/TCE can be degraded anaerobically by reductive dechlorination, where the chlorinated ethenes act as electron acceptors. Each step in the process occurs under specific redox conditions and is carried out by different microorganisms. The first steps from PCE/TCE to cis-dichloroethene (cDCE) can be carried out by a variety of microorganisms, whereas dechlorination of cDCE to ethene has been documented only in the presence of Dehalococcoides. Biological remediation can be applied by bioaugmentation (injection of electron donors) or by bioaugmentation (injection of dechlorinating microorganisms and electron donore), the latter being successful at several sites. The use of bioaugmentation has been suggested as a follow-up technology after thermal treatments.

One advantage of combining biological and thermal remediation technologies is that elevated subsurface temperatures after heating can stimulate metabolic activity. Although conditions during thermal treatment are similar to those reached in an autoclave, some microorganisms survive and are capable of degrading various hydrocarbons. Microbial investigations carried out as part of this work demonstrated that, although the genetic diversity decreased after heating in closed microcosms, functional and catabolic diversity reoccurred within 400 days after heating. However, little is known about the post-thermal redox conditions and the survival of dechlorinating microorganisms, which control the potential for reductive dechlorination.

The work in this thesis demonstrated that reduced conditions could be obtained in the field after full-scale ERH and that microorganisms present after heating were capable of dechlorinating TCE to cDCE. This activity was not observed in closed microcosms heated to 100°C for 10 days. It suggested that microorganisms, capable of dechlorinating TCE to cDCE, survived the harsh treatment in the field or were transported into the treated area with groundwater during cooling and prior to sampling of aquifer materials. Also, a release of dissolved organic carbon (DOC) was observed in the aqueous phase of microcosms that were closed and heated, but not in field samples collected after ERH. This suggested that DOC was either not released at the field scale or transported downstream of the heated area with groundwater. Released DOC can stimulate reductive dechlorination.

Despite an inflow and/or survival of microorganisms after ERH, dechlorination was weakened in half of the treatments, while it remained the same in the remaining microcosms as compared with dechlorination in unheated microcosms. The environmental conditions demonstrated lower redox activity, similar/lower DOC concentrations and similar pH and alkalinitities after ERH.

TCE was not dechlorinated or dechlorination stalled at cDCE in heated microcosms. Microcosms were therefore bioaugmented using a mixed culture (KB-1TM) containing Dehalococcoides, sulfate reducers, methanogens and fermentors. Upon bioaugmentation, dechlorination of TCE to ethene was observed in the majority of microcosms, including laboratory-heated and in-situ heated aquifer materials. This demonstrated a potential and need for bioaugmentation after ERH.

The combination of thermal treatment and enhanced bioremediation can be applied either concomitantly or sequentially. The application of the two technologies concomitantly would involve thermal treatment of a hot spot that is surrounded by biological active zone created by the addition of electron donors alone or in conjunction with bioaugmentation in the perimeter zone. Temperatures in the perimeter zone can be elevated due to conductive heat transfer from the thermal treatment. The elevated temperatures are shown to increase metabolic dechlorinating activity. Bioremediation can, at these sites, be applied at temperatures of approximately 30°C. Sequential thermal treatment and bioremediation can also be applied. In this process, bioremediation is initiated after thermal treatment when temperatures have decreased to approximately 30°C. Finally, the solutions can be combined, where biological treatment is used both in the perimeter zone and inside the thermally treated area during cooling.
When thermal treatment is applied in combination with bioaugmentation, an optimum temperature of approximately 30°C for rapid dechlorination should be the aim. Electron donors are also commonly added during bioaugmentation to obtain reduced subsurface conditions and reductive dechlorination. Electron donors can further stimulate dechlorination of TCE to cDCE, which can be carried out by a variety of subsurface microorganisms. Electron donors can therefore be added at higher temperatures (at the beginning of the cooling period) to obtain anaerobic conditions and dechlorination of TCE to cDCE.

The focus of this thesis was the combination of thermal treatment and bioremediation for reductive dechlorination. However, the combination of these two technologies can also be applied in respect of aerobically degraded contaminants such as oils and BTEX. Furthermore, this combination has the advantage that microorganisms capable of degrading various hydrocarbons have been observed to survive thermal treatment.

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