Thermal treatment

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Why in-situ thermal remediation, ISR?
Basics of thermal technologies
Operating windows
A successful example of steam-air-injection
Therefore ISR - Conclusions

What you can expect

Groundwater table
DNAPL density > water
LNAPL density < water
NAPL = Non-aqueous phase liquid (not miscible with water)

Remediation technologies needed

LNAPL – DNAPL problem

Why thermal treatment?

\[ T_1 = 20°C \]
\[ T_2 = 70°C \]

ca. 2 cm

Photos: A. Winkler
Thermal treatment

Fluid properties - f(Temp)

- thermal enhancement
  - SVE (e.g., Geodesorb, Joule resistance heating)
  - Steam injection
  - High temperature treatment

- surface tension $\sigma$
- vapour pressure $p_v$
- density $\rho$
- viscosity $\eta$

$T_1 = 20^\circ C$

$T_2 = 70^\circ C$

<table>
<thead>
<tr>
<th>Property</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>80 → 69</td>
</tr>
<tr>
<td>TCE</td>
<td>87 → 74</td>
</tr>
<tr>
<td>PCE</td>
<td>121 → 87</td>
</tr>
<tr>
<td>m-Xylene</td>
<td>144 → 93</td>
</tr>
</tbody>
</table>

Steam distillation

Increasing temperature: $20^\circ C \rightarrow 80^\circ C$

and vapour pressure

- Water: factor 20
- PCE: factor 15
- Xylene: factor 19

Reduction of boiling point by steam distillation (azeotropic point):

- Benzene: $80 \rightarrow 69^\circ C$
- TCE: $87 \rightarrow 74^\circ C$
- PCE: $121 \rightarrow 87^\circ C$
- m-Xylene: $144 \rightarrow 93^\circ C$

Thermal in-situ technologies

- Convection $\rightarrow$ Conduction
- Ohm $\rightarrow$ di-electric

- Steam- / Steam-Air - Injection
- Conductive heating, thermal wells (electric or hot gas)
- Electric resistance heating
- RF- / Radio-frequency heating

- organic compounds (LNAPL & DNAPL)
- increase of vapor pressure of contaminant by heating of subsurface / steam distillation
  - by factors enhanced extraction rates
- Extraction of contaminants as gas (SVE Soil Vapour Extraction)
  - fast and reliable (and controllable) remediation process
  - selection of technique dependent on site conditions and “composition” of contaminants (mixtures)
  - expert knowledge required

Operating windows

- 10 °C
- 50 °C
- 100 °C
- 150 °C

- thermally enhanced microbiology
- steam distillation (co-boiling) of many LNAPL and DNAPL
- contaminant transformation due to other chemical processes
**Steam – Air – Injection (SAI)**

**Characteristics**

**Operation windows**
- DNAPL and LNAPL, light and medium volatile, boiling points < 180°C
- UZ: Unconsolidated soil, mean to good permeability (silt → gravel)
- GZ: Pore aquifer (sand to silt)

**Thermal radius of influence (groundwater)**
- Permeability: 0.5 – 5 x 10⁻⁴ m/s
- Steam propagation: 3 - 5 m radius for 150 kg/h steam
- Advantage: anisotropic soil structure

**Features**
- Simultaneous remediation of aquifer and unsaturated soil zone
- Possible structural changes in highly organic soil structures (peat layers) → settlements?

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**Conductive Heating**

**Characteristics**

**Operation windows**
- DNAPL and LNAPL, light and medium volatile, boiling points < 250°C
- UZ: Low permeable soil layers (fine sediments, silt, clay, …), permeability up to 10⁻⁸ m/s
- GZ: For special conditions feasible, to be proved by pilot investigations

**Distance of heating elements in the range of meter (function of site)**

**Features**
- During drying of the soil permeability for SVE can significantly increase
- Beware of possible settlements (clay layers,…)
- Low operating and maintenance costs
Radio Frequency / RF Heating

Principle of heating

- Comparable to Microwave oven
- Heating by internal friction
- Dipole (e.g. water) or other polar structures are activated by vibration

- Direct heat generation in the soil volume
- High flexibility (temperature programmes)
- Can be applied for dry and humid, sandy and tenacious materials, e.g. soils

From Dr. Ulf Roland

Field case: Steam-Air-Injection

Impressions from the site in 2005

Site Karlsruhe Durlach

Slaughterhouse of 1574 ➔ Dry cleaner

Guidelines and tools

Guidelines

- In situ Thermal Treatment (ISTT) for source area remediation of soil and groundwater

Tool for Design Steam-air-injection
Contaminant source PCE
Former dry cleaner: Leaking sewage system below the historical building
PCE in the unsaturated zone, capillary fringe and saturated zone (silt, clay 5 m b.g.s.)
PCE max. 3,800 mg/kg in vadose zone
60 mg/l in groundwater

Groundwater contamination:
plume: > 300 m
PCE concentration up to 350 µg/L

Geology / remediation concept
S-A-injection:
7-8 m b. g.s.
max. 200 kg/h
SVE:
100 - 150 m³/h
GW-pumping (cooling water)
1-3 m³/h

Remediation: implementation
Site owner: Stadt Karlsruhe
Remediation planning and contracting: consultant dplan (& VEGAS)
Operation: Züblin Umwelttechnik
Scientific assistance, monitoring and remediation control: VEGAS & dplan
Advisory board: RP-Ka, City of KA, EPA (LUBW) of Baden-Württemberg

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Thermal treatment

Hans Peter Koschitzky

SAI below the building

Thermal treatment

Drilling and installation of wells

Drilling and installation of wells

Field installation: remediation

Groundwater and soil vapour extraction, activated carbon filter

Exhaust chimney SVE

Extraction well and temperature measurement

Temperature development during remediation

Thermal treatment
Heat propagation: compartment 2

Contaminant removal by SVE

Development of CHC in groundwater

Summary and some numbers of remediation (1)

- Total duration incl. drilling works 70 weeks
- Duration of remediation 42 weeks (ca. 30 weeks steam-air injection)
- Contaminant removal mass 500 kg CHC (incl. pilot)
- Remediation goals achieved concerning CHC concentration
  (10 mg/m³ in soil vapour, << 10 µg/L in groundwater)
- Impressive reduction of groundwater contamination
  - before: 60,000 µg/L
  - two years after: < 5.0 µg/L down to not detectable
Summary and some numbers of remediation (2)

- **costs** total budget ca. 600,000 €
  - 25% drilling and construction
  - 25% consumables, energy (mainly gas for steam production)
  - 50% for plants installation and operation
  ➔ specific costs: ~ 180 €/to soil

- **Energy balance**: 470 kWh/m³ soil (84% heat; 16% electric)
  total consumption: 780 MWh (thermal energy)
  153 MWh (electrical energy)

Therefore ISR

- ISR can be used under difficult and narrow conditions (even below buildings)
- ISR reduce remediation time at minimum by one order of magnitude
- ISR can reduce the total energy consumption by a factor 2
- Cost for subsurface heating and on site treatment (Soil vapour and groundwater) are approx. similar

Conclusion

- ISR can help to solve our contamination problems
- But - no “universal” remedy exists
- use ISR carefully ➔ expert knowledge is needed
  ➔ Detailed site information is needed to chose an optimum solution
- Invest money in a serious site investigation
- Invest in (lab experiments, special problems) and pilots
  ➔ Both will save money and at least led to a cost and eco efficient and sustainable solution
Thanks for your patience and your interest

Any questions?