Thermally Enhanced In Situ Source Zone Removal

- in-situ source removal
- organic contaminants boiling point up to approx. 200°C
- LNAPL & DNAPL
- non cohesive & cohesive soil
- unsat. & satur. zone

Comparison 'cold' SVE with THERIS

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<th>Time [d]</th>
<th>CVOC Mass Flux from Source Zone [kg/d]</th>
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Conventional 'cold' SVE

- conventional soil vapor extraction (SVE): usually several years of operation
Thermally enhanced in situ source zone removal

**Target:**
- liquid contaminant (10 °C) ⇒ gaseous phase
- short remediation time

THERIS = Thermally enhanced in-situ remediation with thermal wells

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Steam-Air Injection: Field of Application

**vadose zone:** high to medium permeability (gravel to sandy silt)

**saturated zone:** porous aquifers
- K: 5 x 10⁻¹ to 1 x 10⁻³ m/s (sand > silt) for radial steam propagation:
  - 3 - 5 m in radius for 150 kg/h steam (120 kW)
- the higher anisotropy the wider steam propagation

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Zeitz - Impressions From The Pilot Field

- horizontal radial steam expansion > 2.5 m in the saturated zone
- reduction of benzene concentration in soil vapor > 99%
- removal of contaminant mass > 95%
- to be achieved during six months (1600 m³ of soil)

Zeitz - Heating Of The Subsurface

- target average temperature in subsurface > 75°C
- cooling (SVE)
**Zeitz - Heat Propagation**

- Target: radial steam extraction > 2.5 m in the saturated zone.
- Extraction process:
  - day 44
  - day 50
- Symmetric steam propagation
- "Thermal radius" ~ 5m
- Operation of two wells.

**Indication of Remediation Progress by SVE**

- Reduction of benzene concentration in SVE by 99%.
- Removal of more than 99% in soil (soil vapour-soil eq. Kₕ-method)
- 0.16 mg benzene / kg soil.
- Soil sampling eight months after steam-air injection confirmed
- 0.1 mg/kg for unsaturated zone and 0.5 mg/kg including saturated zone.

**Zeitz - Mass Extraction of Benzene by SVE**

- Target: Reduction of benzene concentration in soil vapor > 99%.

**Set up and working principle of dielectric soil heating**

- 380 V 13.56 MHz
- MTC & MUX
- RF generator

**Applied electrode geometries**

- Parallel plates or net-shaped electrodes
- Arrays of rod-like electrodes (optional: also used as extraction wells)
- Radio-wave antenna

**Similar to microwave oven**

- Fast re-orientation of polar molecules (e.g. water) or other polar structures in the external electrical field.

**Interaction within the material**

- Heat formation.

**ISRFH with a modular RF system**

**Zeitz - Summary**

- Heating of Subsurface
  - Effective heating to exceed target temperature.
  - Effective, fast & wide-ranging steam propagation in saturated zone.

- Remediation Progress
  - Mass extraction by "cold" SVE and air sparging (59% of total mass).
  - Remediation target achieved by SI (35% of total mass in 13 weeks).
  - Minor mass of Benzene in saturated zone: approximately 300 kg (~ 4%).

- Remediation goals
  - Mass removal: more than 99% of Benzene extracted (6.75 to Benzene).
  - Groundwater: reduction of benzene concentrations by 75%.

**Arrangement for ISRFH project**

- RF unit
- Manifold
- RF generator
- Process control system
- Power
- Cable

- Sensing head for p, T, c
- 3 m
- Electrode distance
- Needle
- Matchbox
- 4 electrodes / extraction wells (optional also used as shielding)
- 9 points for vapour sampling.

**Thermally enhanced in situ source zone removal**

- Arrays of rod-like electrodes
- Parallel plate or net-shaped electrodes
- Dielectric soil heating
- Water / Alternating Current (RF) generator
- Thermally enhanced in situ source zone removal
Thermally enhanced in situ source zone removal

**Electrode / extraction well**

- **Site characterization**
  - **Soil:** very inhomogeneous
  - **Groundwater table:** 8.5 m bgl
  - **Lignite:** > 9 m bgl
  - Treatment of the **unsaturated zone** between 3 and 7 m bgl.
  - **Contamination:** mainly benzene < 3.5 g/kg, variety of aromatic and aliphatic VOC

**Temperature profile**

- Temperature distribution in a soil volume of about 300 m³ after 60 d RF heating with 15 kW
- **VOC concentration**
  - Increase in VOC concentration by a factor of 4 to 8

**ISRFH – new electrode design**

**ISRFH with a modular RF system**

- Temperature profile
- VOC concentration

**ISRFH – Main Results**

- The demonstration project consisted of three stages:
  1. “cold” SVE (24 days)
  2. RF heating alone (18 days)
  3. combined SVE + RFH (36 days)
- App. 300 m³ were heated to a mean temperature of 54°C.
- The **radius of influence** for RF heating was **about 5 m**.
- SVE supported heat transport in the soil.
- Extraction of VOCs was significantly enhanced by heating although quantification was difficult due to interference with the soil around the demonstration site (1.3 tonnes were eliminated).

**Site D: BTEX-petr. hydrocarbon remediation**

- **Surrounding SVE-wells**
- **Central SVE-wells**
- **Thermal wells**

Thermally enhanced in situ source zone removal

Factor 100 in mass recovery

Remediation Area

THERIS application

Workshop Area

Street View
Thermally enhanced in situ source zone removal

TUBA-THERIS-TUBA combination @ industrial site

Temperatures after 80 days

Workshop usage during THERIS remediation

Evaluation of the technology

Eurodemo sustainability demands:
- processes understood
- results from applications are well documented
- high contaminant extraction rates
- fast decontamination
- costs & environmental impacts are significantly less

Conclusions
- Thermally enhancements can be efficiently applied for the in-situ remediation of the unsaturated and the saturated zone.
- Thermally enhancements can enable a continued usage of the building during remediation.
- Thermally enhancements consume less energy than 'cold' SVE.
- The quality of site evaluation effects the quality of the design.
- The remediation goals can effect the efficiency.

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