STEAM-AIR INJECTION TO REMOVE CHC FROM FRACTURED BEDROCK: RESULTS OF A PILOT APPLICATION IN GERMANY

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Introduction

In situ thermally enhanced remediation methods (steam-air injection and thermal wells), developed and verified in several field applications by the Research Facility for Subsurface Remediation, *VEGAS,* are proposed for source zone remediation of NAPL in the saturated and the unsaturated zone. Contaminants can be effectively removed within several months if hydrogeological conditions are suitable.

A novel application of steam-air injection was the removal of chlorinated hydrocarbons from a fractured sandstone aquifer. A pilot application was conducted by VEGAS on the site of Biswurm (Villingen-Schwenningen, Germany). Its goal was to determine the effectiveness of the technology in order to design the full scale thermally enhanced remediation scheme.

The pilot remediation lasted from March 2009 until September 2009. After two weeks of "cold" soil vapour extraction an air-sparging phase was operated for four weeks followed by a steam-air injection of 19 weeks. Different zones of the aquifer were treated stepwise, starting with the base of the aquifer. The concurrent treatment of both the groundwater fluctuation zone and the unsaturated zone resulted in a mass removal rate of up to 8 kg CHC per day. The remediation was completed by a cooling phase of approximately five weeks.

Site description and remediation concept

Below the former incineration plant for liquid organic waste (CHC, BTEX) of Biswurm in a fractured sandstone formation a contaminant source zone is estimated to extend over 2,800 m^2. A detailed site investigation estimated a total mass of 10 to 100 tons of CHC in the sandstone aquifers. The concentration of CHC in the groundwater ranged from 1 mg/l in the saturated zone to up to 40 mg/l in the surface water drainage system (6 m bgs.). The content of CHC in the soil vapour was up to 4 g CHC per m^3 in the source zone and 200 mg/m^3 in the surrounding area.

Underneath 3.5 m bgs, fractured platy sandstone (sos) forms the upper aquifer, separated from the underlying lower aquifer (fractured siliceous sandstone, smk) by a thin layer of mudstone at approximately 22 m bgs. Underlying is bed rock granite at 37 m bgs. Both aquifers are confined. The pressure head in the confined aquifers is approx. 5 to 8 meters above the upper confinement, corresponding to a water level in the wells at approx. 12 m bgs.

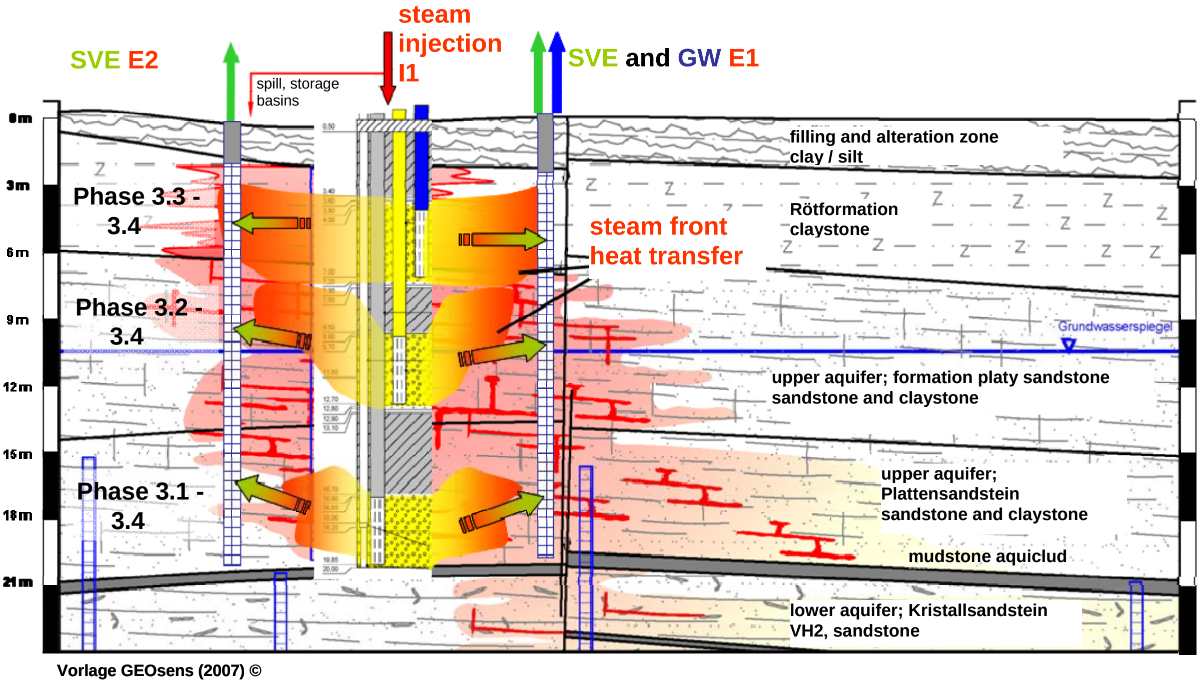

Figure 1: Soil profile and set up of injection and extraction wells (I1, E1 and E2)

Following the geological formation on the site steam-air was injected on three different levels: (1) on top of the aquiclude (mudstone) of the upper aquifer (saturated zone), (2) on the elevation of the groundwater level and (3) into the unsaturated zone (fig. 1).

In general the propagating steam heats the saturated and unsaturated zone by condensation, while the air component acts as an inert carrier gas and transports the pollutants to the extraction wells. Considering the fractured sandstone aquifer and the claystone formation of the unsaturated zone with a low permeability there are two main processes related to heat transport. Steam-air will flush the fractured system, dewatering the fractures. Steam is condensing in the pores, thus transferring the heat to the sandstone. The heat transfer from the fractures into the sandstone is conductive. Therefore it was intended to inject as much steam as possible (maximal injection pressure) in the fractured system and to sustain the propagation process as long as the sandstone matrix is being heated up.

The mixture boiling point of the two-phase-system steam and contaminant (PCE and TCE) is about 84°C. Aim of the steam-enhanced remediation was to exceed this temperature and to maintain the higher temperatures for several weeks to evaporate the contaminants. Moreover the steam and heat propagation on the different levels were to be determined for a safe design of the full scale remediation.

Implementation of the pilot injection

The test field extended to 20 m depths and 12 m in diameter (2000 m³ in volume). One injection well (I1) with three separated injection levels was operated with a power of 105 kW during steam-air injection. Four soil vapour extraction wells (E1, E2, GW8 and D2) surrounded the injection well (fig 2). The soil vapour extraction was operated under medium vacuum (100 mbar) and a total discharge rate of 70 - 110 m³/h. The heat propagation was determined along 12 temperature profiles (lances T1 – T11b) each equipped with 11 temperature sensors (117 Pt100 sensors). The lances surrounded the injection well on different distances in the radial-symmetrical test field. The source zone was hydraulically contained downgradient by two wells (GW11, GW12) operating in the upper aquifer (sos) and one well (GW10) in the lower crystalline sandstone (smk).

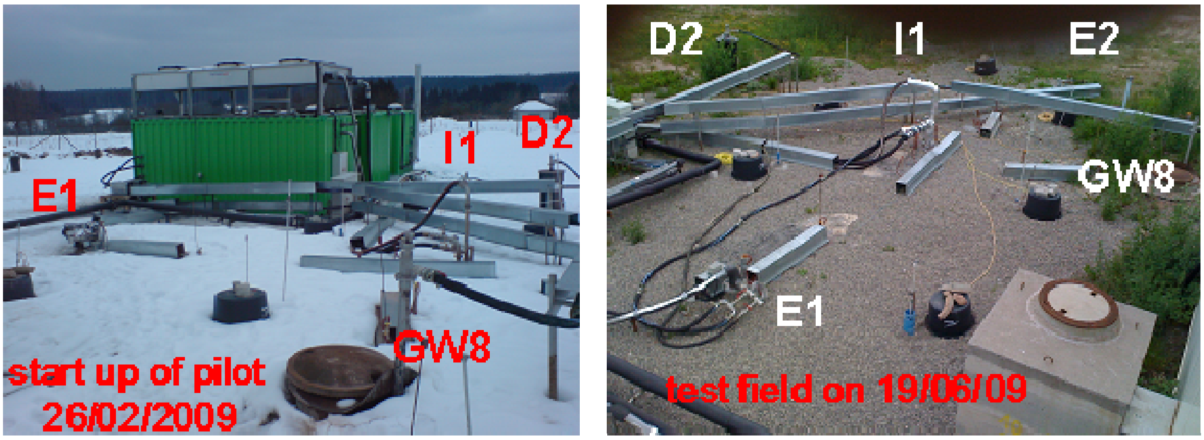

Figure 2: Mobile remediation unit (MOSAM) and test site

The process equipment for thermally enhanced remediation is integrated in the mobile remediation unit MOSAM, owned by the UFZ GmbH, Leipzig. MOSAM is designed for thermally enhanced pilot remediation activities and includes all equipment which is needed.

Heat propagation

The main focus of the pilot trial was the investigation of the propagation of the steam front. It is characterized by horizontal orientation for all the different levels of injection. No dominant vertical propagation of steam due to buoyancy or the structures of the fractured system was observed. The bedrock material was heated by heat conduction.

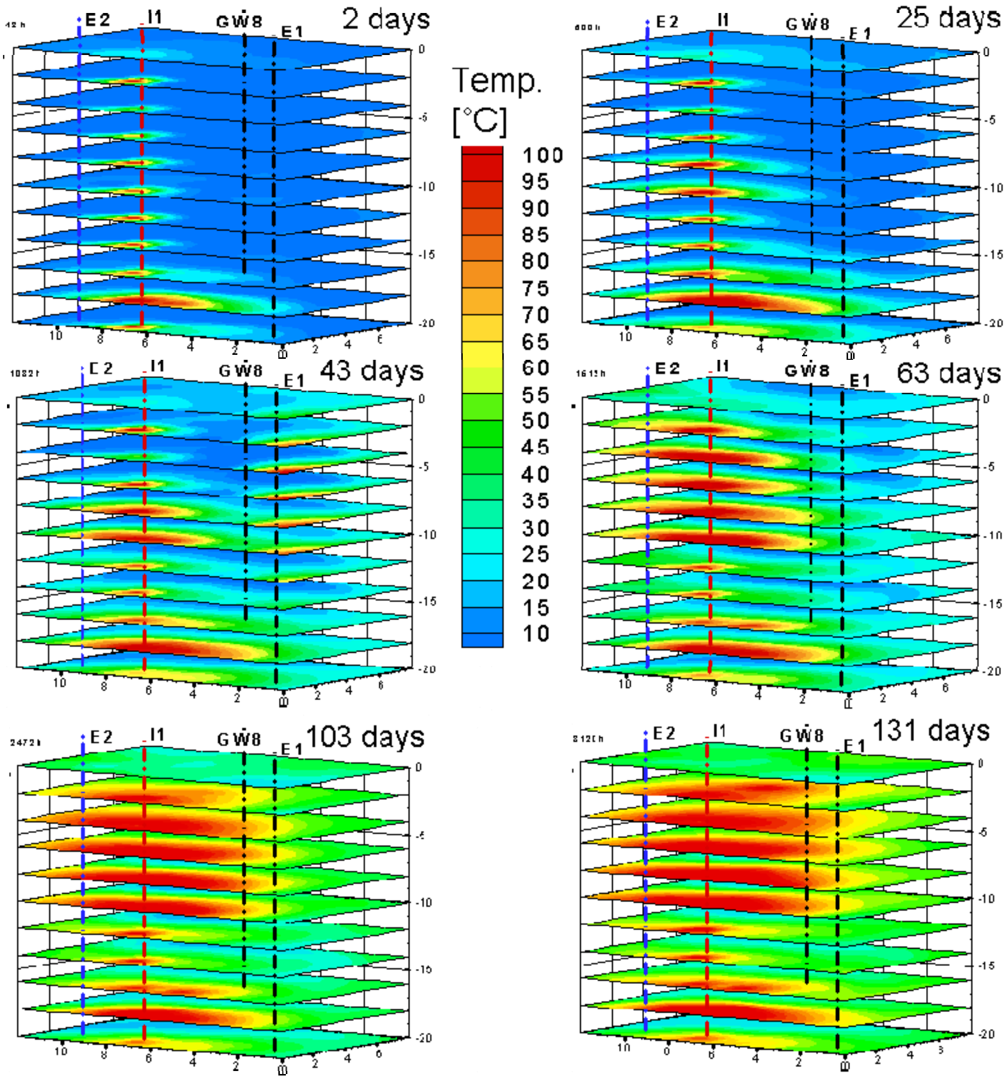

Figure 3: Heat propagation (2 – 131 d of steam injection)

Summary and outlook

The maximum radial steam expansion was limited on the base of the aquifer by heat losses to the high groundwater flow and extended to a radius of 2 – 2.5 m. The thermal radius below the groundwater table as well as in the unsaturated zone was 5 m.

More than 91 % of the total extracted mass (560 kg CHC) was removed from the groundwater fluctuation and unsaturated zones, less than 6% thereof via the groundwater containment (34 kg of CHC). The contaminant mass extracted from the saturated zone (groundwater and soil vapour extraction) sums up to 50 kg of CHC. More than 70% of the removed contaminant mass was extracted during steam-air injection. The CHC values in the soil vapour decreased by 95% from 2900 mg/m^3 to 120 mg/m^3.

The concentration of CHC in the discharged groundwater from the upper sandstone aquifer and the lower siliceous sandstone aquifer were continuously decreasing during the first eight weeks of remediation. Initial values ranged from 2 to 6.4 mg CHC/l groundwater. The final concentrations were between 80 and 180 µg/l in the treated upper aquifer. In the lower aquifer the CHC-concentration was less than 90 µg/l. No rebound effects were detected/seen three weeks after termination of the pilot operation.

The design for the full scale application shows an estimated cost of 2.6 million EUR to treat 40,000 m^3 of sandstone in approx. three years of steam injection. To reach the same objective, a standard pump and treat system might last more than 100 years.

The environmental agency of Baden-Württemberg (LUBW), the regional council (RP Freiburg) and the community of Villingen-Schwenningen support the future application of a thermally enhanced remediation of the site by steam-air injection. The decision about the further procedure will be made within the next few months.

Acknowledgement

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More Info

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