Project No. 22 Thermal In-situ remediation of the unsaturated zone by steam injection			
Location Former hazardous waste disposal site, Mühlacker, Germany	Project Status finished	Contaminants TCE, BTEX	Technology Type steam injection
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	Costs Documented? yes	Project Size pilot scale	Results Available? yes

1. INTRODUCTION

Combined steam injection and soil vapour extraction can accelerate and improve the clean-up of contaminated unsaturated soils due to significant changes in contaminant properties with increasing temperature. The main effect is the dramatic increase in contaminant vapour pressures leading to high removal rates in the vapour phase.

A pilot scale demonstration project using this technology has been carried out at a former hazardous waste disposal site near the town of Mühlacker in southwestern Germany.

2. BACKGROUND

In the late 1960s a disposal site for hazardous wastes containing chlorinated solvents and galvanic sludges was opened in a forest near Mühlacker. The wastes were deposited within a layer of silty loam which was considered to be impermeable enough to protect the subsurface underneath from being contaminated by the leachate of the waste site. Nevertheless, by the late 1970s, contaminants had migrated through the unsaturated zone below which consists of highly heterogeneous weathered sandy marl and were detected in the underlying keuper gypsum aquifer 30 m below ground surface. Detailed site investigation lead to the conclusion that separate phase contaminants (mainly TCE) were retained by a capillary barrier intersecting the unsaturated zone at a depth of 15 m below ground surface.

Soon after that the site was included in the model site program ("Modellvorhaben") funded by the state of Baden-Württemberg and remediation activities started. The site was encapsulated by sheet piles and an asphalt cover was placed on the surface to reduce the leachate flux from the deposited waste. Remediation of the deposited waste itself and the groundwater zone was conducted as well as conventional soil vapour extraction in the unsaturated zone. Due to the complex nature of the subsurface, in-situ remediation of the unsaturated zone by means of conventional methods was ineffective. To enhance contaminant removal a thermally enhanced remediation scheme was installed in a section of the site where steam can be injected in the highly contaminated zone between 7 and 15 m below ground surface. The total volume of soil to be treated in the target area is approximately 3000 m^3.

The pilot plant was operated by the two companies Züblin Umwelttechnik GmbH and Preussag Wassertechnik GmbH and *VEGAS* from the University of Stuttgart, who conducted the scientific oversight. The pilot study was funded by the "Kommunaler Altlastenfonds" and the city of Mühlacker, represented by the consultant company Weber-Ingenieure GmbH.

3. TECHNICAL CONCEPT

The egg-shaped test field with a diameter of about 20 m consisted of one central steam injection well surrounded by six extraction wells. The extraction wells could be used simultaneously for vapour and liquid extraction. All wells reached to a depth of 16 m below ground surface and were screened from 7 m to 15 m. Steam was generated using a gas-fired 110 kW steam generator. Extracted gases were passed through a condenser. Incondensable gases were passed through a catalytic combustion unit before being vented to the surrounding atmosphere. Condensate was passed through liquid separators where the contaminant was separated from the water. Liquids were removed from the wells with surge pumps, passed through a cooler and passed through a separator to seperate the non-aqueous phase (NAPL) from the water.

In order to measure temperatures in the subsurface up to a depth of 15 m, ten temperature monitoring lances were installed with a total of 100 sensors spaced every 70 cm of depth. Detailed monitoring of gas and liquid flow rates and temperatures was carried out during the pilot test.

4. ANALYTICAL APPROACH

Soil samples were taken and analyzed to determine the extend of subsurface contamination. For this purpose contaminants were extracted from the soil by a solvent and analyzed using the HPLC method. During operation, contaminant concentrations were measured regularly in the extracted vapours and liquids using GC and HPLC methods and a flame ionization detector (FID).

5. RESULTS

After a total of ten months of steam injection, almost complete heating of the target zone has been achieved. The problem of the steam front being displaced by the high water content of the soil material could be overcome by filtering the water particles out of the injected steam. Intermittent steam injection was used to reach a more uniform temperature distribution in the subsurface. Since the completion of the steam injection in March 2001, the test field has been cooling. Altogether, 2800 kgs of TCE have been removed, of which about 95% were extracted in the gaseous phase and the remaining part as solute in condensed water.

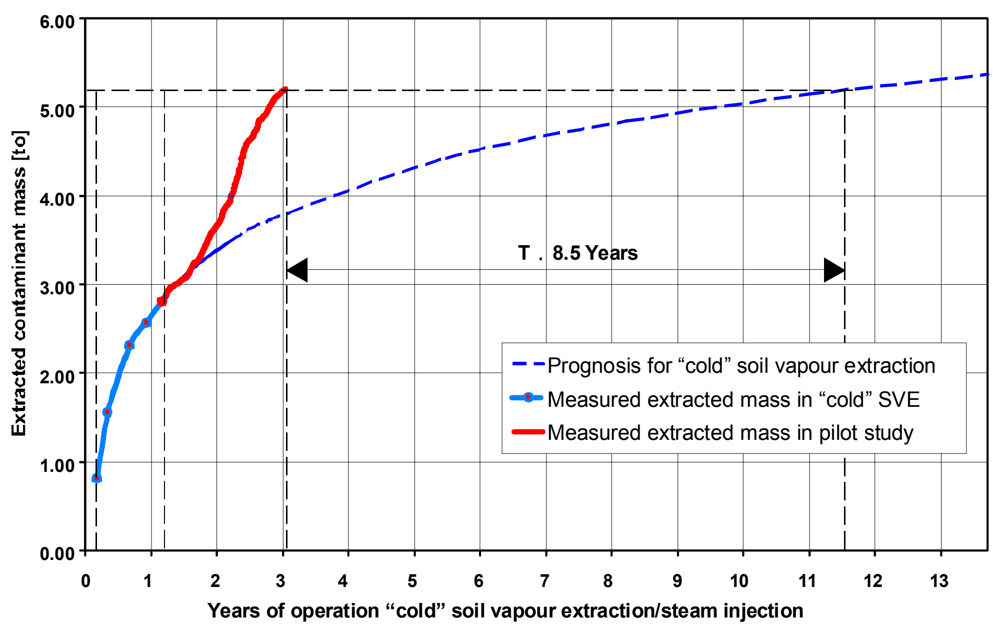

Fig. 1: Mass output performance in steam injection pilot study compared to cold soil vapour extraction

The mass output performance of the pilot study is shown in Fig. 1. At the field site, cold soil vapour extraction had been conducted for approx. one year before the pilot study, resulting in the high contaminant removal rate shown by the line with dots. However, at the beginning of the steam injection pilot study, performance had been decreased. The thermal treatment again raised the removal rate and kept it high during the steam injection. Compared with the period estimated for remediation with cold soil vapour extraction (dashed line), steam injection meant a saving of 8.5 years.

Estimating the performance of cold soil vapour extraction to be expected (dashed line), the conclusion that steam injection resulted in a time saving of 8,5 years for remediation can be drawn.

The project was finished and accounted for end of September, 2001. The cooling process, however, is expected to continue approximately until the end of 2002. Subsurface temperatures will be measured frequently in longer intervals to survey the cooling process.

6. HEALTH AND SAFETY

Safety equipment was used by the staff according to German safety regulations. The pilot plant was equipped with warning systems to control vapour and liquid streams, temperatures and performance of the pumps.

7. ENVIRONMENTAL IMPACTS

Extracted vapours and liquids were cleaned on-site in a treatment facility consisting of a catalytic combustion unit and stripping columns. Thus, emissions to the environment were entirely avoided. Measures for protection against noise were undertaken. Wells were installed to monitor contaminant concentrations in the underlying aquifer in order to be able to take interactive measures in the case of a possible mobilisation of DNAPL.

8. COSTS

The costs for the cleanup of the extracted soil air could only be determined theoretically because, at the field site, the cleaning was coupled to a large plant for groundwater and cold soil vapour extraction and it was not possible to calculate the costs of the pilot study alone.

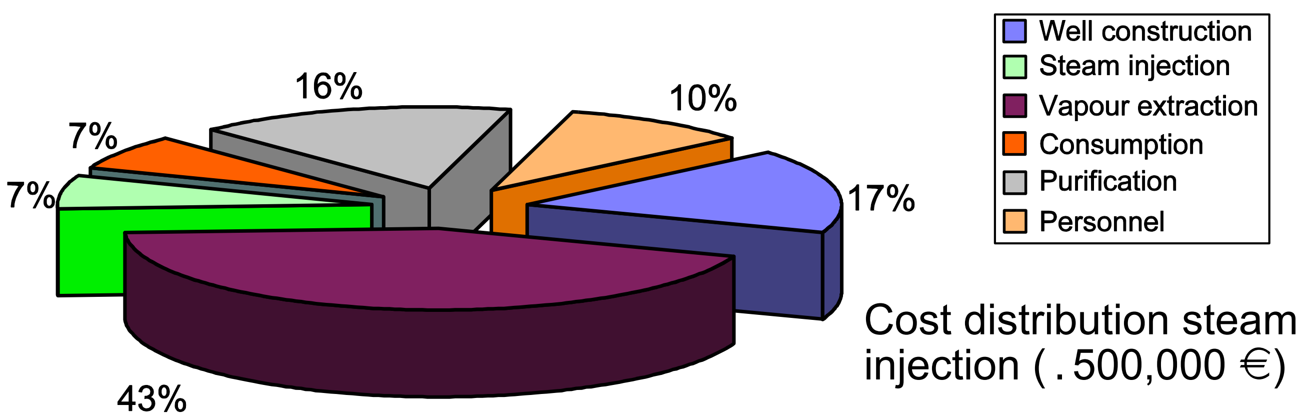

Fig. 2: Total cost and cost distribution of steam injection pilot study

Expenses of about 200,- € per cubic meter and approximately 190,- € per kilogram of extracted TCE were estimated.

Fig. 2 shows the cost distribution of the pilot study. By far the highest expenses were incured by the costly soil vapour extraction plant, which must be fitted for hot gases and treatment of different phases. Energy consumption accounted for only a small fraction. The cost of cold soil vapour extraction calculated for the whole remediation period (see Fig. 1) would have been 50% higher than that of the pilot study.

9. CONCLUSIONS

Despite the low permeability of the subsurface, steam injection could be applied successfully. The problem of the buoyancy of the heat front because of capillary water in the subsurface could be overcome by ensuring only a very low water input. Use of intermittent steam injection towards the end of the heating process led to a more uniform temperature distribution. Conductive heat transport in injection breaks warmed up regions of the soil where convective heat transport was negligible.

10. REFERENCES

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