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1C.27 - Thermal remediation 2

COMPLEX BOUNDARY CONDITIONS FOR IN-SITU THERMAL TREATMENTS (ISTT) CONDUCTED DURING LAND RECYCLING AND REMEDIATION BENEATH BUILDINGS

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INTRODUCTION

In-situ thermal treatments (ISTT) are applied successfully at several sites worldwide. The fields of applications vary from low temperature enhanced microbiological degradation to high temperature degradation of low volatile compounds (Figure 1). For volatile organic compounds (VOC) like chlorinated hydrocarbons (CHC), benzene, toluene or xylene (BTEX), the co-boiling of water and non aqueous liquid phase (NAPL), named steam distillation, is a process, dominating the progress during source zone remediation. This process occurs mainly between 60 to 100°C.

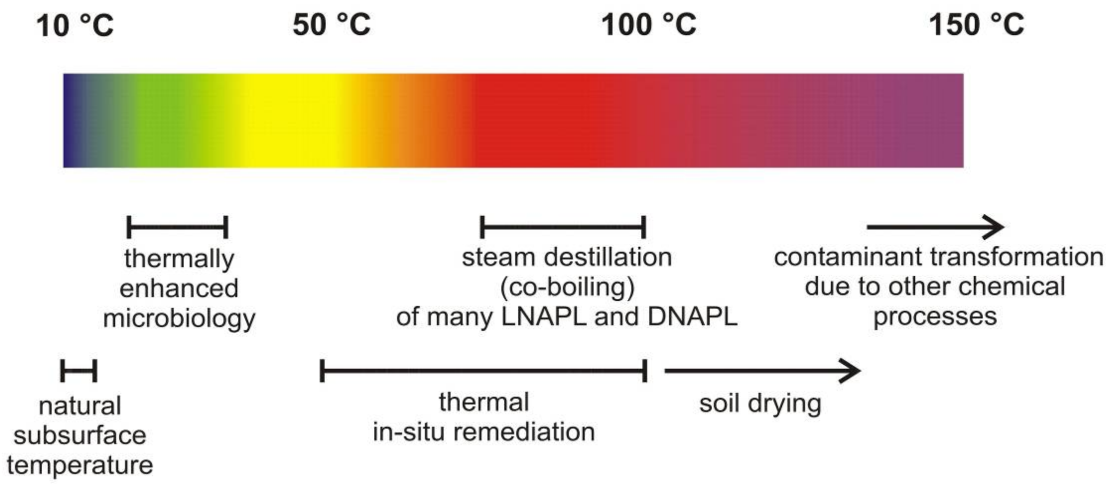

Figure 1: Application ranges of sub-surface heating for remediation and fields of application of these guidelines [HIESTER ET AL. 2013 [1]]

In the recent past, more complex projects are conducted as well with treatments close to the surrounding infrastructure like in inner city sites or next to or beneath buildings. Often, usage of infrastructure and buildings must be enabled as well during the remediation works, e.g. for housing or industrial production processes [HIESTER & SCHRENK 2008 [2]]. Furthermore, ISTT has been successfully applied during land recycling projects. Combining in-situ remediation projects with buildings under construction demands a professional project management to solve the complexity caused by a high amount of individual processes, often interacting with each other.
For ISTT of CHC, the selection of the heating method is mainly dominated by the geological and hydro-geological conditions in the contaminated layers. Steam injection and steam enhanced extraction (SEE) is applied usually in sandy layers with a hydraulic permeability > 10^{-6} m/s, whereas thermal conductive heating (TCH) with thermal wells enables an efficient heating in silty, loamy or clayey formations, as well as in case layer thickness of several meters (Figure 2).

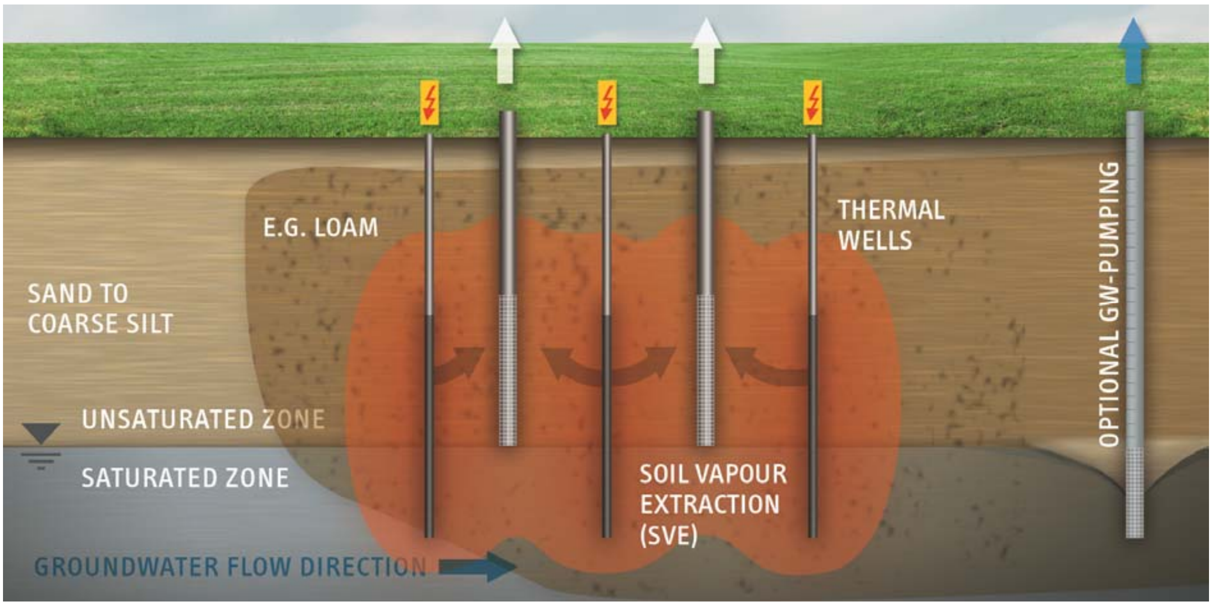

Figure 2: Scheme of thermal conductive heating (TCH) with thermal wells (THERIS method)

This article presents ISTT projects with several design restrictions caused by neighbours, structural engineering or industrial production in the treatment areas during remediation. The remediation management team (RMT) coordinated the interactions between remediation activities and third party purposes. Difficult processes are named and hints for further projects are summarised. Furthermore, the impact of more complex boundary conditions on the ISTT design, operation procedure and measurement devices during the remediation are described.

HISTORY AND BOUNDARY CONDITIONS

At the foundry site in Austria, casting products with magnesium and aluminium have been produced since 1958. Since 1964, several open washing and degreasing plants were operated over years by using chlorinated hydrocarbons, mainly tetrachloroethene (PCE) and trichloroethene (TCE). Losses by the standard manipulation in the 1960th and 70th caused soil and groundwater contamination, characterised by three CHC source zones beneath and close by buildings.
In the beginning of the 1990th CHC contamination was detected. Conventional soil vapour extraction was operated in two source zone to recover 36 kg in one zone from 1993 and 1996 and 207 kg CHC in another zone until the year 2002. Additionally, a pump and treat system was operated to recover CHC from the groundwater. Until 2009, in total approx. 350 kg CHC were recovered. Nevertheless, CHC source zones in the unsaturated soil as well as groundwater contamination were still present, even after 15 years of remediation works. Related to the remediation time, the average annual mass recovery varied for these conventional systems between 4 to 22 kg/a (Figure 15).
Further site evaluation was conducted in contract for the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management. Additional to the known source zones, a third source zone close by a former storage room for oil, paint and chemicals was detected. Soil vapour concentrations for CHC varied between 2,900 to 9,900 mg/m^3. To prevent further CHC migration and to enable a continued casting operation, a reliable in-situ remediation strategy was needed. Focusing on the updated site evaluation, TCH in two source zones with moderate to low permeability and steam injection (SEE) with air co-injection in a stratified layered geology were selected as preferred methods. A central pump and treat system was redesigned and operated continuously to avoid downstream migration of dissolved contaminants with the groundwater. Both, recovered soil vapour and groundwater were treated by active carbon.

CASE 1: IN-SITU THERMAL TREATMENT DURING SIMULTANEOUS FOUNDATION AND SUPERSTRUCTURE WORKS FOR A NEW FACTORY BUILDING

A VOC contamination was determined in low permeable (cohesive) silt and clay layers beneath an existing storage building in the groundwater fluctuation zone up to 8 m bgs. The base area contaminated by more than 10 mg/m³ in the soil vapour has been explored to approx. 460 m². Herein, approx. 175 m² were contaminated by more than 100 mg/m³ CHC and approx. 55 m² were contaminated by more than 500 mg/m³ CHC in the soil vapour (Figure 3).

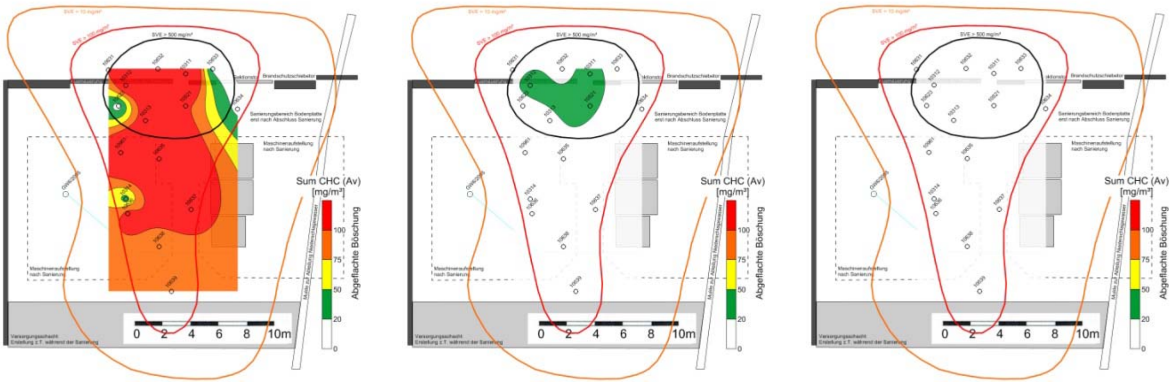

Figure 3: Soil vapour concentration before remediation (left), after 2 months TCH (middle) and after 3 months TCH (right)

Due to changes of site owner's facilities, this existing building was demolished and replaced by a new factory building (Figure 4). Requirements for the CHC source zone removal were a rapid, seriously and efficient remediation concept. In-situ strategies were compared with conventional source zone excavation and disposal as well as with drilling and replacement. Evaluating costs, time frame and interface with the timeframe for superstructure implementation, in-situ thermal treatment (ISTT) was evaluated as the most economical and efficient technology. To heat the low permeable loam, TCH by using thermal wells was applied to vaporize the CHC (THERIS method).

Rainfall infiltration can cause cooling effects in an ISTT field. To reduce the amount of rainfall infiltration into the treatment target zone (TTZ), the TCH field was covered by a construction foil (Figure 4, right).

ISTT works were not allowed to interrupt foundation works or superstructure installation for the new building. Thus, a close interface management between involved specialists for the installation of the new building like pile foundation team, superstructure construction team and remediation specialists was established to enable a failure-free operation of each lot.

Figure 4: Beginning of the CHC source zone remediation: Demolishing of former chemical storage building (left), TCH remediation field (right)

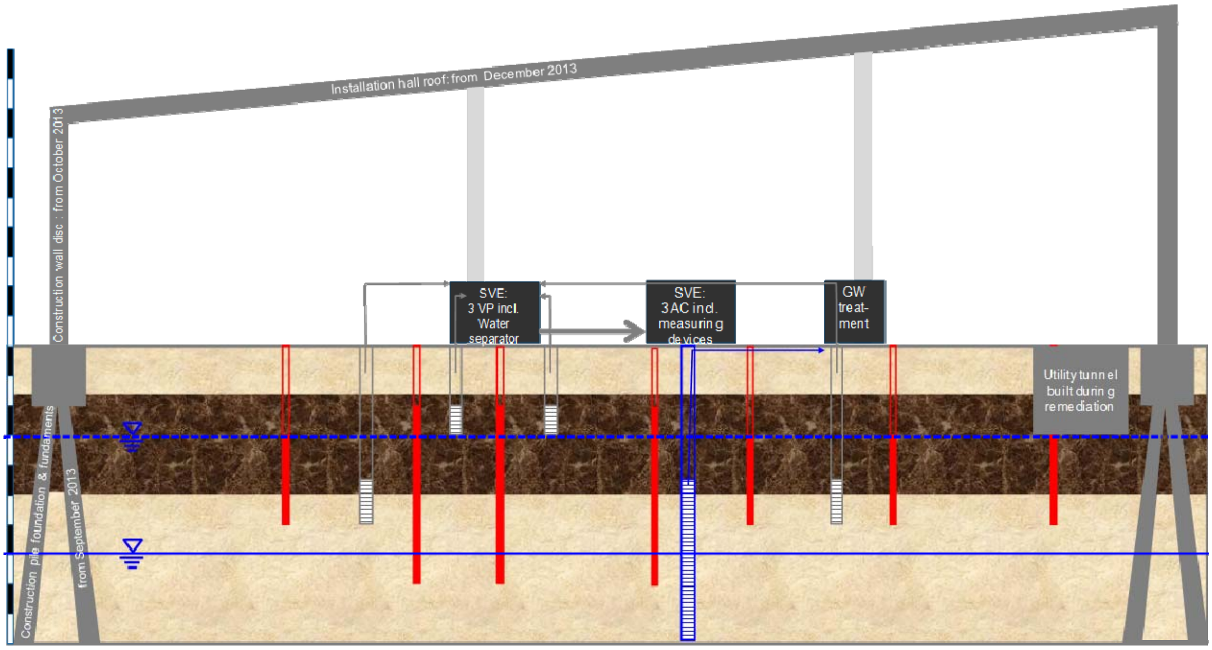

Figure 5: Schematic intersection of the remediation field: TCH remediation (THERIS method) during simultaneous foundation and superstructure works for a new factory building

Design revision for ISTT as well as for foundation and superstructure was undertaken by an interdisciplinary team of experts. Parts of the design did not match with the location of installations and the scheduled time frame of the remediation works. Thus, parts of the foundation and superstructure including location of gates in the outer shell had to be redesigned. Moreover and because building activities were conducted close to the remediation area, it was found, that foundation and super-structure works may change boundary conditions for the ISTT field almost weekly (compare Figure 4, Figure 6, Figure 7). To enable a better work flow the superstructure implementation, parts of the remediation field were allowed to be used temporarily for equipment storage for superstructure works.

Figure 6: Midterm of the ISTT: Concrete works for building superstructure crossing the TCH field (left), excavation for the basement close by TCH remediation

Two months after starting ISTT, about 3 m deep excavation for the basement close by the operated ISTT was conducted (Figure 6). The top of the heater zone of some thermal wells in the ISTT field was almost in a similar height (Figure 5). The SVE was continuously operated, and no CHC concentrations were found in the vapour in the excavation pit. Pressure monitoring in the ISTT field detected a negative pressure of approx. 150 mbar even at 8 m distance from recovery wells under operation.

To enable a detailed and rapid remediation management, remote controlled automated monitoring systems for remediation process relevant parameter like subsurface temperature, pressure and concentration and discharge in the SVE were established. For different reporting dates, contamination in soil vapour based on single well measurements is illustrated in Figure 2. To enable a maximum of transparency in the remediation process and progress, co-ordination measures about ongoing works with other specialists as well as with authorities was conducted on a weekly base. ISTT was completed within 4 months with no disturbance of the new factory building installation. The roof of the new building was closed before removing the last SVE-container from the TCH field and the outer shelter was closed immediately after removing the ISTT equipment. The former remediation area is superstruct now by an aluminium die casting machine with a weight of approx. 100 tons.

Figure 7: End of ISTT: TCH field inside and outside the new building. Two weeks later, TCH field was removed and outer shelter incl. roof of the new hall were closed.

To enable successful ISTT projects under complex conditions, the remediation management team (RMT) has to involve specialists for non remediation related subsections to coordinate interactions. However, ISTT during a land recycling project is only successful, if RMT and structural engineering (like foundation and superstructure works) cooperate in time to avoid time delay in each subsection.

CASE 2: STEAM ENHANCED EXTRACTION (SEE) BENEATH A BUILDING DURING CONTINUED INDUSTRIAL PRODUCTION

Beneath a building, CHC were recovered by a conventional SVE from 1996 to 2002. Downstream migration of contaminants in groundwater were limited by a pump and treat system. Although 35 kg CHC were recovered by SVE within six years, contaminants beneath the building were still present. To remove the remaining contaminants from the unsaturated zone and to reduce groundwater pollution in a long term perspective, steam enhanced extraction (SEE) was chosen as the most efficient technique to remove CHC during continued industrial production in the building.

During tender design, the CHC contaminated area with concentrations larger than 10 mg/m³ in the soil vapour has been explored to approx. 315 m² (Figure 8, orange dashed line). Within this area, the treatment target zone (TTZ) with more than 50 mg/m³ CHC was investigated with approx. 33 m² (black dashed line = TTZ tender design). To treat this area the installation of two steam injection wells with filter screens in different depths, five SVE wells and four temperature monitoring wells were planned.

During drilling works and well installation, contaminants in soil vapour samples were measured (Figure 10). Highest soil vapour concentration was detected in the boundary located temperature monitoring profile next to the TTZ. Therefore, the TTZ had to be extended. Additional drillings confirmed the extended source zone geometry. The area contaminated with CHC concentrations exceeding 50 mg/m³ in soil vapour has been explored to approx. 290 m² finally (Figure 8, black solid line = modified TTZ), in opposite to the tender design with 33 m².

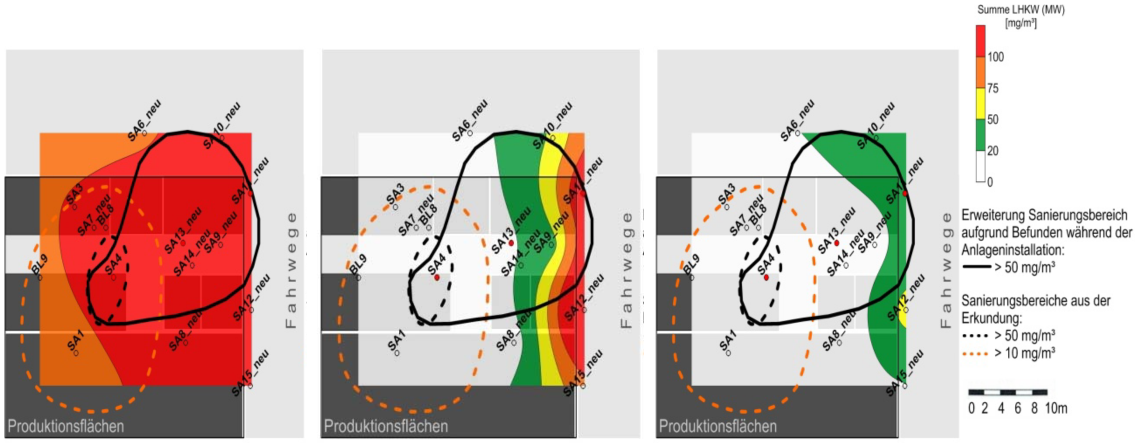

Figure 8: Remediation progress during steam injection: Soil vapour concentration before remediation (left), after 4 months (middle) and after 8 months (right)

During the first drilling campaign, two additional SVE wells were drilled and installed (Figure 9, middle). Steam injection and SVE pipelines were installed in a very sensitive environment, because industrial production had to continue without disturbance during remediation works. Partwise, steam injection wells and SVE wells were located close to machines operation areas and equipment storage areas for the production (Figure 12, blue lines). Steam boiler and compressor for steam-air-injection as well as SVE equipment were installed in containments outside of the building. Pipelines for steam injection and SVE were suspended under the ceiling to avoid damages by the ongoing production. Steam boiler (capacity 100 kg/h) and SVE were connected by programmable logic controller (PLC) communication to avoid steam injection in case of a shutdown of the SVE. Moreover, pressure in the injection line was continuously monitored by pressure sensors. In case of pressure losses in the injection line, steam injection was automatically stopped.

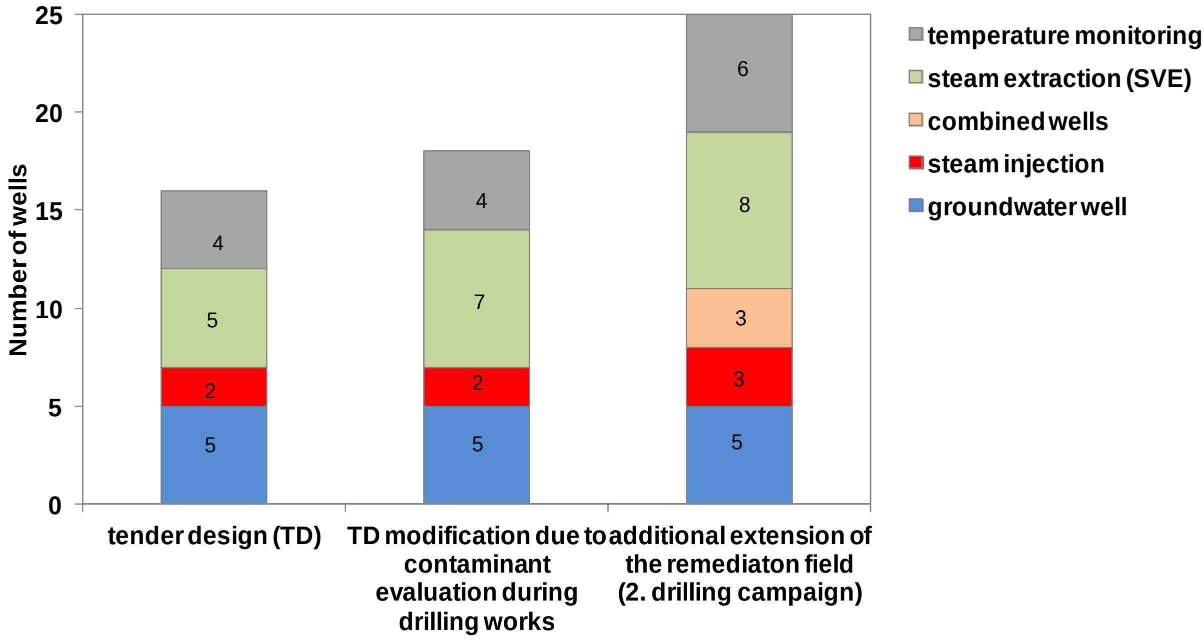

Figure 9: Number of wells during tender design, modified tender and extended remediation

To monitor processes continuously and to enable a rapid remediation management, temperature, flow and concentrations were measured automated by remote controlled monitoring and data sampling systems. Data were evaluated on a daily base and reported to project partners on a weekly base. Installation procedure, monitoring concept and safety devices were confirmed before start-up by client`s health and safety officer, production manager, quality survey team as well as local authorities.

Figure 10: Drilling inside a building during continued industrial production (left), soil sample (middle) and display of steam injection filter horizon (middle and right)

Steam and air were injected at first in the unsaturated zone in the ordinary detected TTZ, afterwards even in the saturated zone. For the deeper steam injection wells, the filter screen was installed in a loamy layer at the base on the saturated zone to inject steam at the base of the aquifer (Figure 10). CHC were vaporised and recovered continuously by the SVE. During this first three months, 2.5 kg CHC were recovered in average per week.

Former soil vapour evaluation wells were still present beneath the building. To observe the impacts of steam injection to CHC indoor intrusion, additional indoor air samples were analysed continuously. Air exchange between indoor and outdoor air could be described as high. However, CHC could be detected permanently in the indoor air (Figure 12, first week). Based on literature values [Grenzwertverordnung [3], TRGS 900 [4]], these concentrations were very low and can be evaluated as uncritical for human health. The permanent presence of CHC in indoor air was a surprising issue, because impacts from the remaining CHC from the former conventional SVE, starting in a depth of 5 m bgs, to indoor air were not expected before the steam injection. It could be demonstrated, that steam-air-injection into the remaining source zone reduced CHC indoor air pollution immediately. The measurement of some detected PCE concentrations in indoor air after 90 days steam-air-injection could not be correlated to the remediation processes or activities from industrial production process.

Even CHC remediation was completed after four months in the tender designed TTZ (Figure 8), CHC were still detected at the boundary of the remediation field. Thus, four additional wells were drilled. To reduce costs, two of these wells were used either for steam injection or SVE (combination well, Figure 9). Two temperature monitoring profiles were installed at the filter screen of two wells.

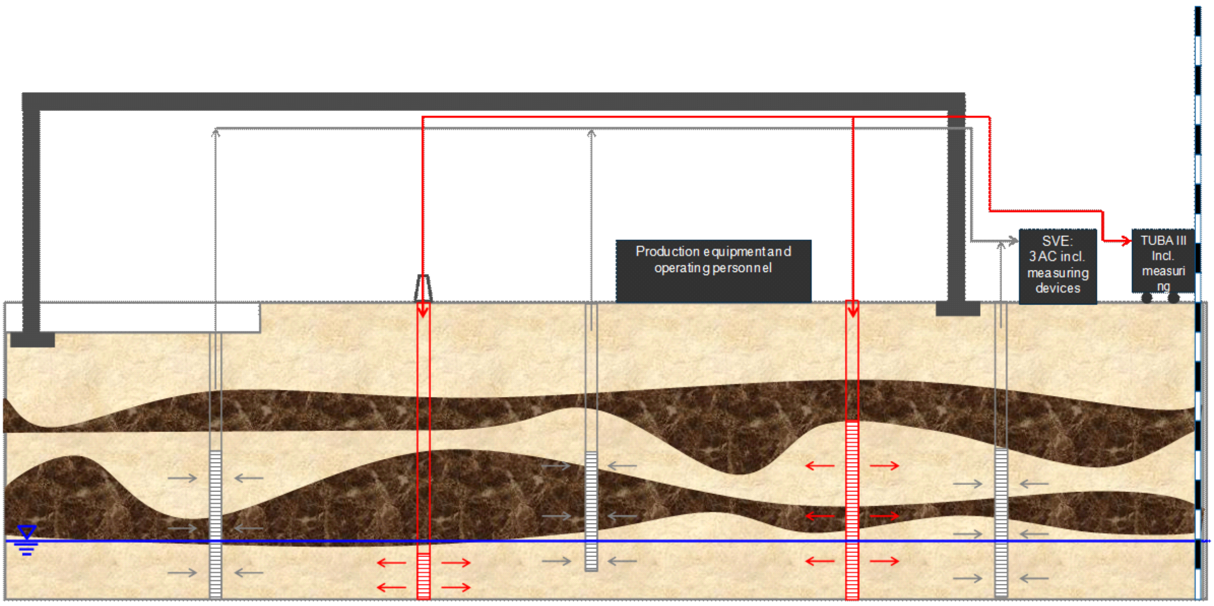

Figure 11: Cross section of the steam enhanced extraction (SEE) beneath a building

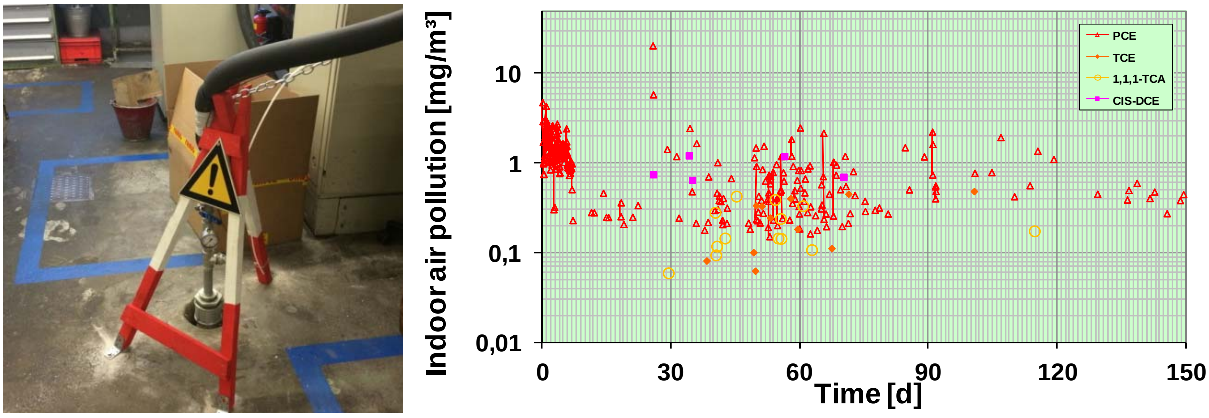

Figure 12: Insulated steam injection pipe beneath machinery and storage area (left, blue line), reduction of CHC indoor air pollution during steam injection

EFFECTS OF INTERMITTED AIR-CO-INJECTION INTO CONTINEOUS STEAM INJECTION

To operate equipment gentle during high summer season, to reduce waste heat and the potential risk of damages by overheating, air-co-injection into the continued steam injection was interrupted after 1.5 hours for 30 minutes. As an example of the effects, a day period from end of August 2014 is shown in Figure 13. During this period, 100 kg steam per hour were injected in the wells SA13 and SA14 (Figure 8, middle), about 11 m distanced from the temperature monitoring in SA11 (Figure 13).

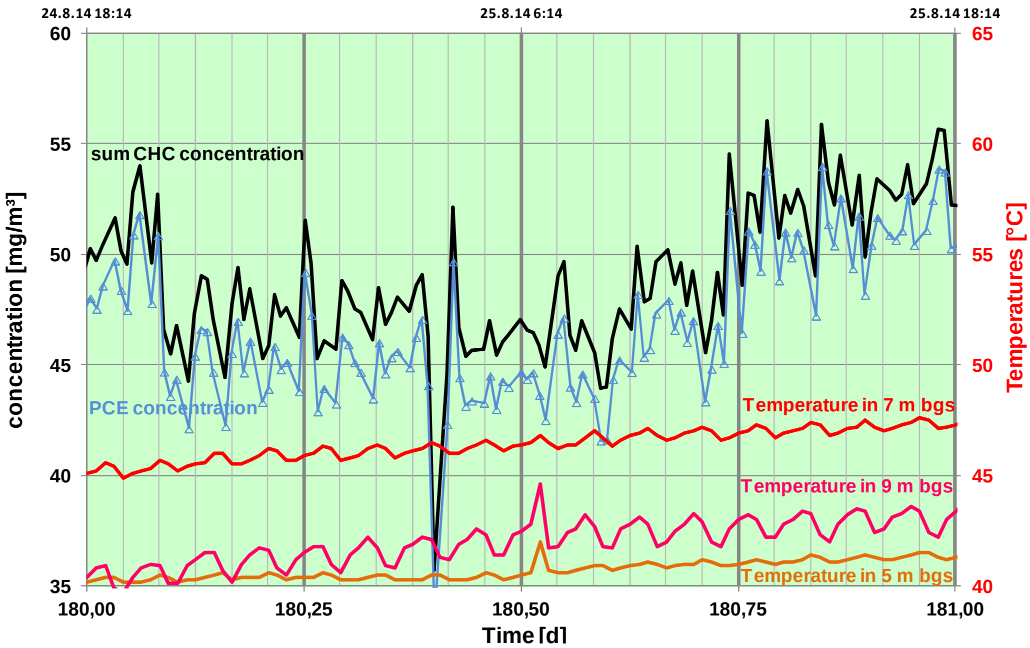

Figure 13: Effect of intermitting air co-injection into a continued operated steam injection

SVE was operated to recover CHC in SA11 in SA12 and SA15. BL8 was operated to avoid uncontrolled steam migration. Because the area around BL8 has been treated before, BL8 effected a dilution of the contaminants from SA11, SA12 and SA15. The concentrations, presented in Figure 13 are the mixed concentrations of all four operated wells.

Well known from lab experiments and former field applications, air-co-injection prevents contaminant condensation and accumulation at the steam front. Furthermore, the radius of influence of the injected heat is increased, because less steam condenses close by the injection well. Even approx. 11 m distanced from the injection wells, in three different depths, the rapid, repeatedly and pulsate cooling of the recovered soil vapour as an effect of an interrupted air-co-injection could be observed. Due to the dilution by the air-co-injection, simultaneous to increasing temperature at the SVE recovery well, CHC concentrations in the SVE system drop down usually. For the overall mass balance, this effect is minor but repeatable and dominated by PCE as the main contaminating CHC at this site. Nevertheless, both effects cause layers of different permeability to be affected by this intermitting air-co-injection, which is beneficial for the remediation process in stratified layers.

TEMPERATURE EFFECTS OF INTERMITTING STEAM-AIR-INJECTION IN STRATIFIED LAYER

After about six months, steam injection was interrupted completely to enable SVE to address a larger pore volume due to the changed pressure conditions in the subsurface. Air-co-injection into the steam was continued for 1.5 hours and interrupted then by 30 minutes. Steam or steam-air-mixture was injected in well SA11 for five hours and then interrupted for one hour (Figure 8, Figure 14). SVE was operated on SA9, SA10, SA12 and SA15. Temperature monitoring data in SA12 in 8 m, 4 m and 6 m bgs and SA11 in 5 m, 7 m and 9 m bgs are shown in Figure 14. The distance between injection (right profile SA11 incl. filter screen) and SVE (left profile SA12 incl. filter screen) was approx. 11 m. Injection well SA11 was located in a sandy layer, whether SA12 was surrounded by a gravely silt (illustrated as well as a blue box) with some embedded preferential flow paths. Without steam injection, groundwater flooded approx. the last meter of the injection well and approx the last 0.5 m of the recovery well SA12.

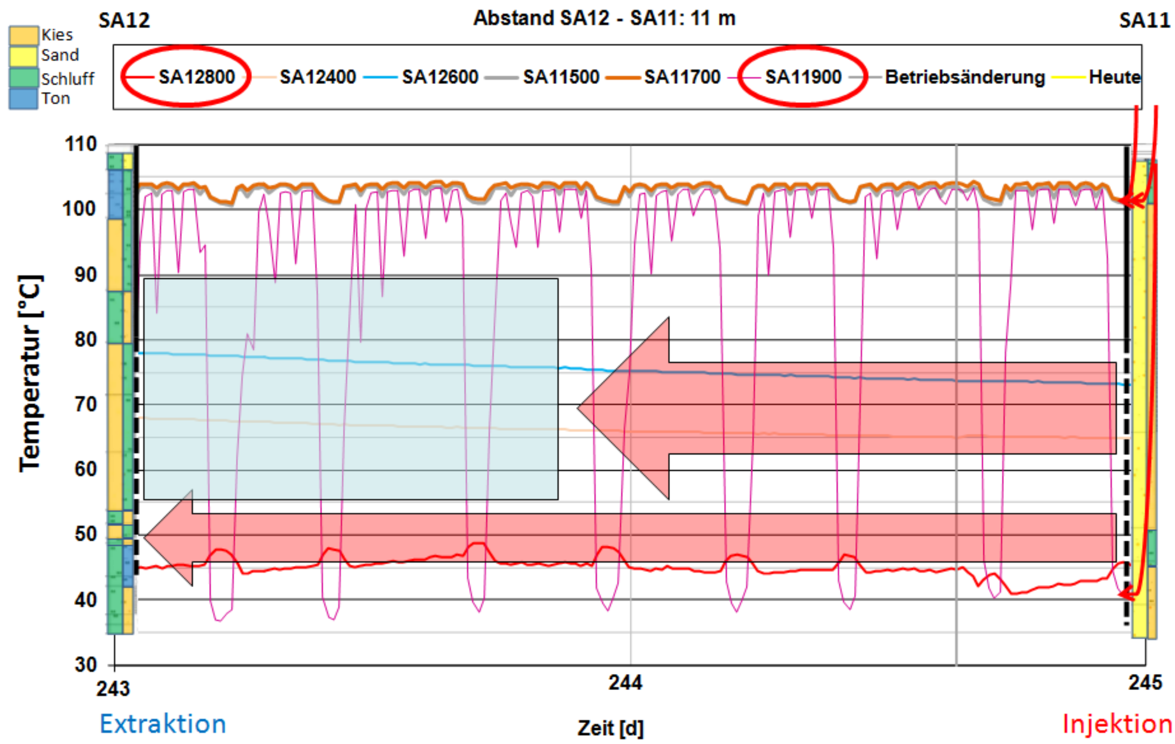

Figure 14: Temperatures during intermitting steam injection at the injection well and a corresponding SVE well

At the injection well SA11, the interruption of the air-co-injection effects the decreasing temperature in the injection depth at 5 and 7 m bgs. However, in the groundwater affected filter screen, the missing air-flux caused a collapse of the steam front and a flooding of the bottom of the filter screen, illustrated by temperatures below 100°C in a depth of 9 m bgs. The cooling effect is reduced due to higher groundwater temperature in the environment of the well after permanent steaming, but still present after several hours. The cooling effect is tremendous by reaching temporarily less than 40°C while interrupting the injection for one hour.

At the recovery well SA12, a continuous cooling in a depth of 4 m and 6 m bgs could be observed. This is caused by cooling of the silt by SVE. Steam had been injected into SA12 weeks before heating the subsurface in that area actively. But, more interesting is the periodic increase of temperature in SA12 in 8 m bgs, when injection in SA11 is interrupted. This indicates that during interruption of steam injection, other preferential flow paths are addressed by the SVE. The rising groundwater level during interrupted steam injection might have an impact as well. A detailed interpretation of this field data is difficult, due to missing detailed groundwater level monitoring in the area of interest.

SUMMARY AND CONCLUSION

ISTT can be applied successfully under complex boundary conditions. A detailed process understanding, continuous monitoring and permanent remediation management is needed for an effective application. Regular communication and cooperation with all project partners like authorities, health and safety officer, production manager, supervisor for superstructure works, architects and others is essential for the transparency of needs and decisions.

Compared with conventional SVE and pump and treat at the site, the powerful remediation process of ISTT can be illustrated by comparing the average annual CHC mass flux per method and source area. To recover the same contaminant mass with pump and treat at this site, remediation work would take more than 50 years, assuming a constant mass recovery for the hydraulic system.

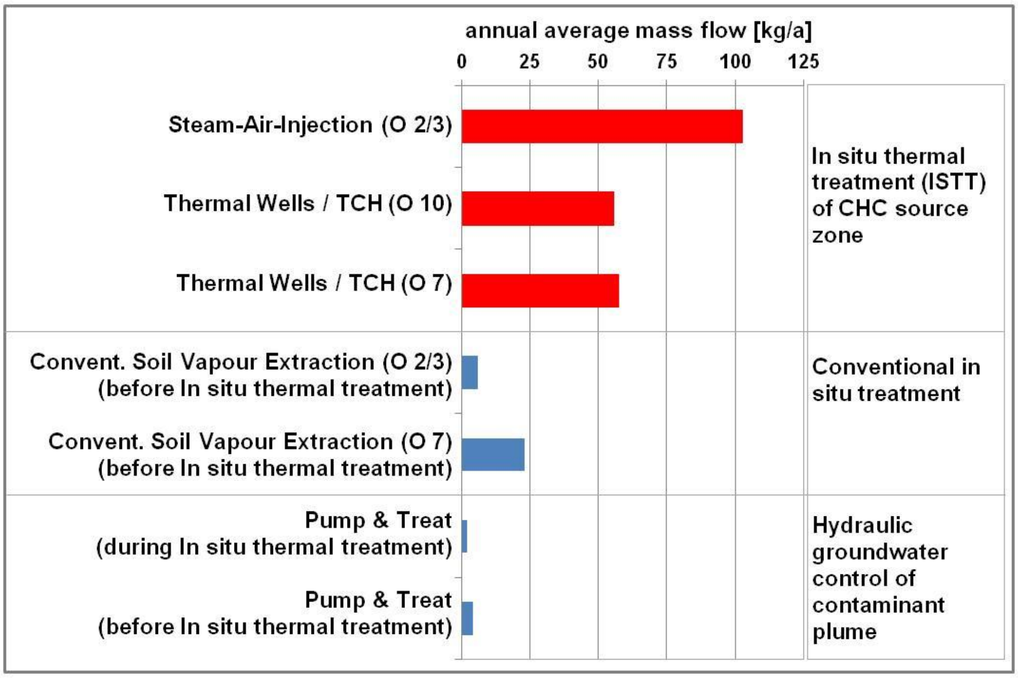

Figure 15: Average mass flow [kg/a] for different remediation methods

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