Denmark Drycleaner

In Situ Thermal (Steam Enhanced Extraction – Thermal Conduction Heating)

Site Name: Drycleaner in Denmark
Site Location: Knullen 8, Odense, Denmark
Technology Used:

- In Situ Thermal Treatment
  - Steam Enhanced Extraction (SEE)
  - Thermal Conduction Heating (TCH)

Regulatory Program: Region of Southern Denmark
Remediation Scale: Full
Project Duration: 105 days

Site Information: The site has been operating as a dry cleaning facility from 1978 to present. From 1978 to 1992, water containing high concentrations of tetrachloroethene (PCE) was disposed of into a concrete separation tank located under the facility about 13 ft below ground surface (bgs). There, PCE was separated from water and accumulated at the bottom of the tank. Through minor cracks in the concrete, PCE migrated out of the separation tank and through 36 ft of till clay down to a high yielding, confined sand and gravel aquifer. In addition, a PCE plume had migrated 3,000 ft from the source area toward two municipal wells one mile away, which supply over 100,000 citizens in the city of Odense.

Contaminants: Soil and groundwater were contaminated with PCE. The major source area was located around the separation tank and extended laterally up to 50 ft and vertically from about 13 to 49 ft bgs. The majority of the PCE mass was located in the clay till layer and the upper 13 ft of the underlying aquifer in the source area. Dry weight PCE concentrations were found up to 2,200 parts per million (ppm) in the clay till above the aquifer, and up to 27 ppm in the aquifer. The target treatment zone was estimated to contain more than 7,700 pounds of PCE.

Hydrogeology: The upper layer of fill from the surface to 6.5 ft bgs is silty sand. Minor parts of the fill are sandy clay. From 6.5 to about 36 ft bgs is clay till that is slightly sandy, silty, and contains small amounts of gravel. However, the clay till is homogeneous within the treatment area and has no off-sand layers or sand laminae. The lower part of the clay till is saturated. Groundwater in the clay till is found at approximately 9.8 to 16.4 ft bgs.

Beneath the clay till (below about 36 ft bgs), is a meltwater deposit of sand and sandy gravel. The bottom of the aquifer is approximately 92 ft bgs, where an additional layer of clay till is located.

Soil layers and the upper zone of the aquifer can be described as shown in Table 1:

Table 1. Description of the soil layers and the upper part of the aquifer

Feet (bgs)	Soil Type
0 to 6.5	Fill – silty sand and some sandy clay
6.5 to 36	Clay till – slightly sandy and silty with small amounts of gravel
36 to 41	Gravel – fine to medium, sandy
41-45.9	Sand – fine to medium, slightly gravely
45.9-92	Sand – medium to coarse, gravely

Project Goal(s): The goal of this project was to remove the PCE hotspot. Specifically, the remedial objective was to reduce PCE concentrations in the source area (defined as area with soil PCE concentrations above 10 ppm) to 5 ppm or below.

Cleanup Approach: Excavation of the contaminated soil and remediation using thermal treatment were considered for the site. Excavation was estimated to involve a smaller area and soil volume to be treated than thermal remediation. In addition, calculations showed that energy consumption by excavation would be about 5% of the energy consumed by thermal treatment. However, physical constraints posed by the location of the contamination—under a building with active dry cleaning operations—would not have made it possible to remediate the same area by excavation as by thermal treatment. Also clay is general not conducive to remediation by technologies that require direct contact (in situ oxidation, reduction, or biostimulation). Therefore, conductive heating was chosen as the preferred remedy for addressing contamination in the clay.

The presence of the heavily contaminated and highly transmissive sand and gravel aquifer that was also part of the remediation effort raised the question as to whether conductive heating would be the most efficient technology for both. Numeric simulations using the Steam, Thermal and Advanced processes Reservoir Simulator (STARS) were performed to model different approaches for heating the source area. Simulations were carried out for two scenarios:

- TCH as the only heating source in both clay and sandy soil; and
- TCH used to heat the clay portion of the soil, while steam is used to heat the sandy portion of the soil.

In the first STARS simulation, water in the aquifer was heated to boiling point using TCH so that evaporated water and contaminants could be ventilated out of the area. This process led to cold groundwater entering the treatment zone, requiring additional heating. The simulation thus showed that it is necessary to keep the inflow of groundwater into the treatment zone at a minimum, in order to prevent use of the supplied heating energy for incoming water rather than for removal of the contamination. Therefore, in situ thermal desorption as the only heating method was determined to be inefficient because the time and energy needs would be too high to achieve complete PCE removal in an economically feasible manner.

The second STARS simulation was performed using two different approaches: one in which TCH wells were installed through the clay layer into the sandy aquifer, and one in which TCH wells were installed only in the clay till layer. Both scenarios involved using steam in the sandy aquifer. The first scenario showed that water migrated into the clay till around the TCH wells. The cause of this was suggested to be higher permeability around the borings due to heating. In the second scenario, water migration was prevented by installing the TCH wells only into the clay till. This increased remediation efficiency in the clay till, but had no effect on remediation efficiency in the sandy aquifer. This scenario showed that heating only the clay till layer while injecting steam into the aquifer would minimize the upward flow of cold water and allow the desired temperature (100ºC) to be reached within 6 months to remediate the clay till and the upper 13 ft of the aquifer.

Both simulations showed that parts of the modeled area reach a temperature of 50°C about 5 ft bgs and up to 115°C about 16 ft bgs. These temperatures would be detrimental to the active pipelines in the fill layer below the dry cleaning facility, which cannot withstand temperatures above 50°C to 60°C. It was determined that in the full-scale application, ground surface heating could be avoided by increasing ventilation in the fill layer below the concrete floor.

The upward hydraulic gradient and the permeable sandy aquifer posed a challenge for TCH. In addition, the treatment was to be conducted without disturbing ongoing dry cleaning operations (see Figure 1 for system setup inside the dry cleaning facility). This limited access for drilling, placement, and operation of equipment, which needed to be conducted between dry cleaning machines, walls, cables, and pipes beneath a false floor.

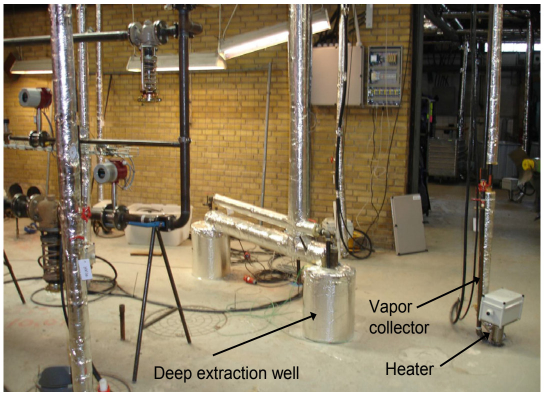

Figure 1: System Setup inside the Dry Cleaning Facility

Courtesy: TerraTherm, Inc.

Both vertical and angled borings were installed to ensure the target temperature would be reached. A detailed fill layer ventilation system was installed to protect sub-slab piping, sewer drains, and lines from overheating. The ventilation system was also designed to prevent condensation of contaminants in the colder areas near the ground surface.

Borings included 45 TCH wells installed in the clay till to 32.8 ft bgs and five steam injection wells to 46 ft bgs (see Figure 2). Over 60 vacuum borings were installed to capture mobilized contamination. Wells were installed within the active dry cleaning facility without interfering with ongoing operations.

Heating and steam extraction began in June 2008 with a power input of 450 kW. The treatment period was estimated at 175 days with a target temperature of 100°C. Actual heating lasted 105 days, when remediation goals were reached.

Project Results: About 46,968 ft^3 of soil were treated using the approach over an area of 2,389 ft^2. About 7,716 pounds of PCE were recovered from the clay till layer, while about 1,102 pounds of PCE were recovered from the sandy aquifer (Figure 3). Remaining PCE mass in the target zone after treatment was estimated to be less than 22 pounds.

Remediation goals were reached at 105 days, 70 days earlier than expected. Average temperature achieved was 102ºC. After the 105 day treatment period, 14 soil samples were collected at different depths from five borings within the treatment area. Recovery rate exceeded 99.75% in the clay till layer and 95% in the sandy aquifer. All samples showed PCE concentrations below remedial goals of 5 ppm, with the maximum PCE concentration in the samples at 4.4 ppm. Five of the samples had PCE concentrations below detectable levels. The average concentration was 510 parts per billion (0.51 ppm).

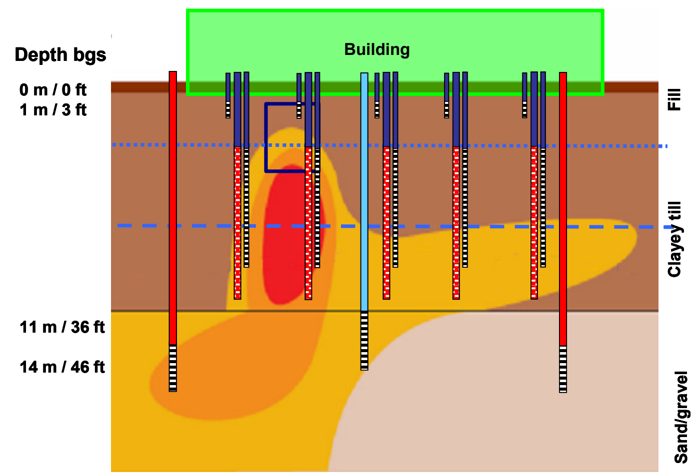

Figure 2: Model of TCH, Steam, and Extraction Wells Under the Dry Cleaning Facility

Courtesy: TerraTherm, Inc.

The energy requirement was calculated to be about 13.6 kWh per 1 ft^3 of soil treated. No soil subsidence occurred during or after the heating. Removal of the source zone had an immediate impact on the mass discharge from the site, which was decreased by at least 300 times by thermal treatment, according to water samples collected in monitoring wells 170 ft downgradient of the source area. The site plume has shrunk considerably since the source was removed and the site is in a long-term monitoring mode.

Sources:

Heron, Gorm. Email communication April 19, 2013.

NIRAS. 2007. Background Information and Scope of Work for Numerical Simulations–Knullen 8 in Odense, Denmark (Afværgeforanstaltninger på Knullen 8, Odense: Termisk Oprensning STARS Modelsimuleringer). http://www.atv-jord-grund-vand.dk/Afholdte_moeder/0803_vinter/Centersal-050308/C13.HenrikEngdalSteffensen.pdf

Nielsen, S.G. et al. 2008. FirstThermal Remediation Using a Combination of Steam and ISTD. In Proceedings of the Sixth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA).

ISTD Remediation in Clay Till: Odense, Denmark. 2009. Krüger A/S. http://www.e-tct.co.il/PDFs/casestudies/organic_carbons/PCE%20Odense%20Denemark.pdf

Skou, H. and H.E. Steffensen. 2009. Remediation of Soil Pollution. Reduction of the Environmental Load by Determination of the Remediation Goals. Green Remediation International Conference November 9 - 10, 2009 Copenhagen, Denmark. http://www.eugris.info/newsdownloads/GreenRemediation/proc_decision_support.htm

Thermal Conduction Heating. TerraTherm, Inc. 2009. http://www.terratherm.com/thermal/tch/index.htm

Project Contacts:

Gorm Heron
TerraTherm, Inc.
661-823-1620
Email: gheron@terratherm.com

Henrik Steffensen
NIRAS
hes@niras.dk

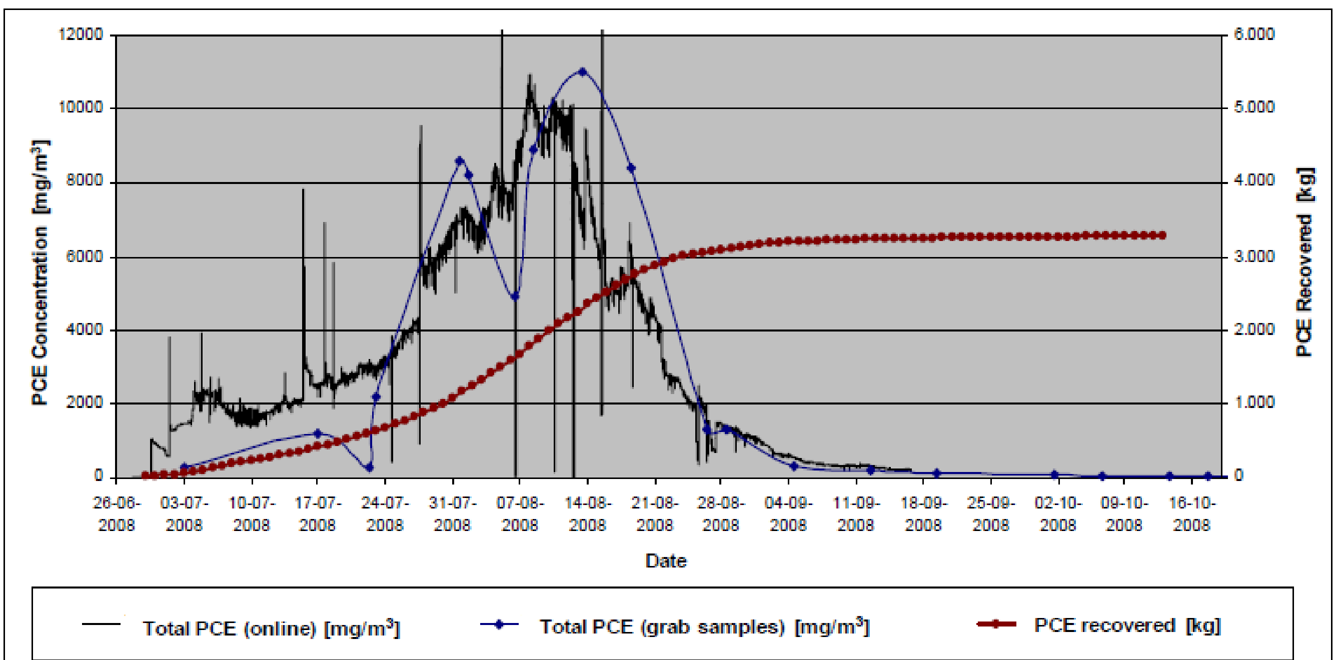

Figure 3: PCE Soil Concentration and Mass Recovered During the Treatment Period.

Courtesy: TerraTherm, Inc.