First European Thermal Remediation of Crystalline Bedrock

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Background. The peninsula of Kvarnholmen is located only 10 minutes away from downtown Stockholm, Sweden with a picturesque view over the sea. Kvarnholmen is undergoing tremendous development to provide housing for the Stockholm residents. Unfortunately, part of the site (29.0000 m^3) was contaminated with PCE, so remediation was required before the developers were allowed proceeding building luxury apartment complexes.

The site posed some significant challenges. The site consists of crystalline rock with very low porosity and few fractures and had to be remediated from 20 m above to 10 m below sea level. Site development had to continue building a bridge to the island touching base right at the treatment area. A road, bike and a pedestrian path through the source zone had to be installed during site installation and kept open during thermal operation. Groundwater below the remediation target zone was also substantially contaminated. Since intact core sampling wasn't feasible an alternative confirmatory sampling program had to be developed.

Activities. Using thermal conduction heating (TCH), it is possible to heat the entire volume of granite independent of porosity and fractures and thereby ensure even treatment of blind end fractures. However, heating and extracting in such a matrix is not trivial. A numerical thermal model was used to simulate heating under different water flow conditions. Based on these simulations, a total of 105 heater wells were installed to 14 m below the surrounding sea level with a total heater length as long as 32 m. Heaters were boosted to deliver 35% more energy below the water table. A row of heaters beside the road, between the road and the bike path as well as heaters adjacent to the pedestrian path allowed for sufficient energy input beneath these infrastructures.

All heater wells were installed with collocated extraction screens installed in a gravel pack with a grout plug at the top and bottom, making individual extraction control possible. Installing the gravel pack around the heaters was done to short circuit as many fractures as possible making a robust and safe removal of vaporized contaminants.

Core sampling was not feasible at this site and a new sampling program was developed. The site cleanup is documented using a multiple line of evidence. This consists of water samples, pore gas sampling, off gas removal trends and temperature monitoring of the entire site.

Lessons Learned/Results. Operations started in January 2017 and power was turned off after 138 days of operation achieving an average temperature of 141 °C in the target zone. Off gas concentrations performed completely as expected starting at 10 mg/m^3 in the beginning of the operation peaking at 1800 mg/m^3 during operation and then decreasing again to 10 mg/m^3 at the end of operation at an average temperature of 141 °C. So off gas removal and temperature indicates thorough cleanup. Most of the water sampling wells are currently dry (August 2017) and waiting for water to return. Pore gas sampling is ongoing and being evaluated. It does pose some challenges to evaluated vapor samples on a 100 °C hot site since the equilibrium is shifted towards the gas phase and therefore these samples will be over conservative compared to a 10 °C situation. The effect of leaving a contaminated water body below the treatment zone is being evaluated as the water is slightly rising back into the treatment zone. All of these data will be ready for the conference and should be used to evaluate future thermal remediation setups.