Advances in Chlorinated Solvent Source Zone Treatment using In-situ Thermal Technologies

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Background

• Site previously subjected to considerable traditional investigation by others (circa £1 million) that had failed to provide a defensible Conceptual Site Model (CSM)

• Client required remediation to be undertaken as part of its corporate risk management policies, and a long term pump and treat scheme was proposed at this point costing up to £15 million

• However, it was believed that through an improved understanding of the hydrogeology, sources, and potential for risk associated with subsurface contaminants, an alternative and more cost effective remedial approach could be developed
Background (2)

• To achieve this objective, the geometry of the plume needed to be understood. ERM therefore used a variety of High Resolution Site Characterisation (HRSC) techniques, including:
  • *Gore Sorber*™ Survey at 155 locations (largest survey of its type in the UK)
  • *Modified Waterloo Profiler* Investigation (Alluvium/shale) – 100+ groundwater VOC samples collected
  • *Discrete Fracture Network (DFN)* Investigation (Bedrock shale and Sandstone) – 450+ pore water samples
• HRSC approach carried out in accordance with Triad principals to collect collaborative data set
• Sustainability a key focus at both site investigation and remediation stage (SuRF UK Framework)
Contaminant Distribution
Refined Conceptual Site Model
Remedial Strategy

- Source zones and ‘plume’ areas fully defined by HRSC
- CWQRA showed theoretical risk to off-site receptor from cis 1,2-DCE
- Vast majority of contaminant mass present in matrix of the shale (long term source)
  - 80% of the mass in 40% of impacted area.
  - Targeted, intensive source treatment proposed in this location (steam injection)
  - Less intensive biological substrate injection in remaining areas (not discussed today!)
- Remediation endpoint of mass recovery to the extent technically and practically feasible was agreed with the regulatory authorities
Remedial Strategy (2)
Steam Injection Design

- A number of full-scale steam injection projects have been undertaken in the UK, since the first application in 2005, with the vapour extraction component traditionally undertaken:
  1. Within a naturally occurring permeable unsaturated zone
  2. One created via de-watering

- At this site field scale pilot tests carried out to assess viability:
  - Steam injection trial (and follow up thermal modelling)
  - Soil Vapour Extraction (SVE)
  - Dual Phase Vacuum Extraction (DPVE)
Vapour Extraction/Pumping/Steam Injection Pilot Trial

Well Array showing SVE and DPVE locations

Soil Vapour Extraction and Steam Enhanced Dual Phase Vacuum Extraction Test Area Infrastructure

Liquid and Vapour Phase Treatment Units
Steam Injection Pilot Test Results (Well 5D)
Steam Injection Pilot Test Results (Well 1D)
SVE/DPVE Pilot Test Results

1. SVE test showed Alluvium was lower in permeability than anticipated and vapours could not be extracted from this formation.

2. DPVE test showed that the shale was found to be too highly transmissive to allow de-watering:
Thermal Modelling

- Injection well spacing and orientation
- SVE/DPVE wells spacing and orientation
- Time required to reach:
  - Treatment Temperature,
  - Remedial objective
- Energy input requirements
- Off-Gas treatment requirements
- Treatment duration
- Cost!
Output Examples – Project Duration

Prediction of Treatment Duration

- Extraction phase
- Dewatering phase
- Heating to 100 °C
- Boiling period
- Cool-down phase

Average temperature (°C)

0 20 50 100

10 days 24 days 66 days 114 days 144 days

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Remediation Design Concept

• Whilst steam could easily be injected, traditional in-situ vapour capture options technically unsuitable

• Re-visited options appraisal – but no other options than thermal available to remove mass from shale bedrock matrix in accordance with project objectives

• Looked at civil engineering options (vent trenches) – but practicality/water management/safety of concern

• Operation of the remediation system was therefore focussed upon:

  1. Heating the clay from beneath to artificially increase its permeability via ‘fracking’ (captured by SVE trenches); and

  2. Development of a ‘Steam Bubble’ to allow vapour recovery through a zone created by boiling the groundwater (captured by vertical DPVE wells)
Key Remediation Challenges

- Difficult hydrogeological setting (confined, high permeability aquifer) to apply in-situ technologies/boil groundwater

- Difficult geological setting (majority of mass in fractured rock matrix) – thermal only realistic option to remove this mass, although not attempted before in UK(?)

- All works undertaken inside a building (vapour management issues, drill rig access, trenches around foundations)

- On-site steam source was used for the works, but had to fully integrate remediation system with this supply to avoid factory shut-downs!

- Process equipment not normally used for brownfield remediation needed to ‘control’ high temperature steam bubble approach (cooling tower/H&S)
Full Scale Well Location Plan
Steam Injection Well Design

- **Shallow Steam Well**: 60 mm stainless steel casing
- **Deep Steam Well**: 60 mm stainless steel casing

**Shallow Well Screen**: 3-5m bgl (2m) (both areas)

**Deep Well Screen**: Steam Area 1: 11-12m bgl (1m) Steam Area 2: 10-11m bgl (1m)
Steam Injection Infrastructure

STEAM SUPPLY

CONNECTION TO SYSTEM VIA PRESSURE REDUCING STATION (PRS)
SVE Trench Design

TRENCH AREA 1 – 11 trenches with 20 risers

- Trench depth ~ 1.8m bgl
- 60 mm HDPE riser
- 60 mm slotted HDPE pipe

TRENCH AND TRENCH RISER WITH CONNECTION TO RECOVERY SYSTEM

TRENCH AREA 2 – 8 trenches with 23 risers
DPVE Well Design

Screened:
Steam Area 1:
- 2.3 - 12m bgl (9.7m)
Steam Area 2:
- 3 - 10.5m bgl (7.5m)

- 115 mm stainless steel casing

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Liquid Phase Treatment System

- PUMPING CHAMBER
- BAG FILTERS
- PLATE HX
- LIQUID PHASE GACS
- SILT SEPARATOR
- FLOWMETER

Liquid Phase Input (pumping & condensate from vapour phase)

effluent drain
Vapour Phase Treatment System

- **Vapour Phase Input**
- **SHELL & TUBE HX (DPVE)**
- **FIN TUBE HX (TRENCH)**
- **HYDROCYCLONE**
- **EXTERNAL COMPOUND AND COOLING TOWER**
- **AIR PHASE GACS AND VENT STACK**

**SIDE CHANNEL BLOWERS (CONTAINER ALSO HOUSES COMPRESSOR & CONTROL PANELS)**
System Monitoring

- Monitoring using thermocouples to determine subsurface temperatures. Real-time assessment of data (refine/calibrate thermal model)
- Vapours/liquid concentrations and flow rates determined, hence estimate of mass recovered could be calculated
- System functionality monitoring undertaken
- H&S monitoring of vapours inside building + Legionella monitoring (cooling tower)
System Performance

Note: Temperature data taken from the top three thermocouples in wells R1-R20
Conclusions

• As a result of fully defined CSM, works completed for £2.5 million (versus the £15 million originally estimated)

• The mass recovery results demonstrate considerable success of the operational approach with total mass removal calculated at circa 1,100kg

• Recovery via wells in ‘steam bubble’ zones and also in trenches due to ‘fracking’ of clay

• The application of this remediation design in a complex geological and hydrogeological setting provides confidence that a similar approach could be taken on other sites where remediation has previously been viewed as technically unachievable