Klozur® SP
Case Study

ISCO-ISS For Remediation of Source Area Soils at a Former MGP Site Achieving Several Site Goals

Site Information

Site: Søllerød Gasværk - Former MGP, Denmark

Lead Consultant: COWI A/S

Technical / Design Support: Geosyntec Consultants

Soil Mixing Contractor: Arkil

Regulator: Capital Region of Denmark

Contaminants of Concern

Coal tar including benzene, naphthalene and phenols in soil and free phase

Application

Source Area Treatment / Tar Impacted Soils

Remedial Approach

ISCO-ISS: Soil mixing using *in situ* chemical oxidation (ISCO) combined with *in situ* solidification and stabilization (ISS)

Results

Achieved contaminant reduction and hydraulic conductivity goals

Site Overview

Soils at the former Søllerød Manufacturing Gas Plant (MGP) site located in Copenhagen, Denmark were impacted by high concentrations of tar and related compounds, including benzene, naphthalene and phenols. Free phase tar has been encountered down to 15 meters (m) below ground surface (bgs). The soil was heterogeneous and composed of sand and silty sand inter-bedded in clayey silt. The targeted depth interval extends from 10 to 15 m bgs, located below an organic rich peat layer. A total of 1,800 m^3 of highly impacted soil is targeted for treatment. The area surrounding the site had previously been redeveloped into residential housing and multi-use commercial developments resulting in critical needs to control noise, odors and site activities due to the limited size of the site and proximity to the residential neighbors.

Remedial Approach & Goals

The overarching goal for the site is to reduce leaching and migration of dissolved phase tar compounds (ie. BTEX, sVOCs, and phenolic compounds) from source area soil to groundwater to help protect a downgradient municipal supply well. Following a review of potential remedial options an *in situ* remedial approach combining the application of chemical oxidants (Klozur® SP) and binders (slag cement) was selected for implementation via soil mixing using large augers.

The combined ISCO-ISS approach was designed to remove the more soluble, mobile fraction of the contamination (lower molecular weight compounds) via chemical oxidation while cementing the remaining higher molecular weight fraction of the tar in place. The addition of cement was also intended to activate the Klozur SP by generating alkaline conditions, significantly improving the kinetics of the ISCO reactions.

The screening criteria for treated soils included both visual and geotechnical performance goals:

- Visual: No visual free phase or soil clods > 6 cm
- Unconfined Compressive Strength (UCS): > 0.35 MPa UCS in 90% or more of the confirmation samples, and no samples with results less than 0.15 MPa after a 28-day curing period
- Hydraulic conductivity: less than or equal to $1x10^{-8}$ m/sec

Bench & Field Pilot Tests

A series of bench scale tests were conducted at Sirem Laboratories in Ontario, Canada. These studies assessed the impacts to leachability, unconfined compressive strength (UCS), hydraulic conductivity (K), and contaminant destruction. Variables assessed included Klozur SP concentration, binder type (Portland cement and blast furnace slag), and sequential versus combined application strategies. Based on the bench testing results the preferred binder blend and Klozur SP dose were selected to be implemented in the field.

The viability of applying reagent blends in the field was then pilot tested with different blends and approaches applied in 5 test columns. The primary objective of the pilot study was to reproduce the results observed in the laboratory under field conditions for the selected reagent blends as well as assess and optimize reagent dosing.

Full Scale Implementation

Following pilot testing of this approach, the full-scale application was implemented in August to September 2018. Klozur SP and slag cement was blended in to the soil at a dose rate of 3 and 8% by soil mass, respectively. The blending was done using a wet soil mixing approach using a 2 m diameter auger with a 100 metric ton drill. The reagents are injected in to the soil during mixing via ports at the auger mixing head.

The targeted treatment area was approximately 188 m^2 with a target interval of approximately 10 to 15 m bgs giving a total approximate treatment volume of 1,865 m^3. Using the 2 m diameter mixing auger and with 17.5 percent overlap between each column, 75 columns were used to treat the target area (Figure 1).

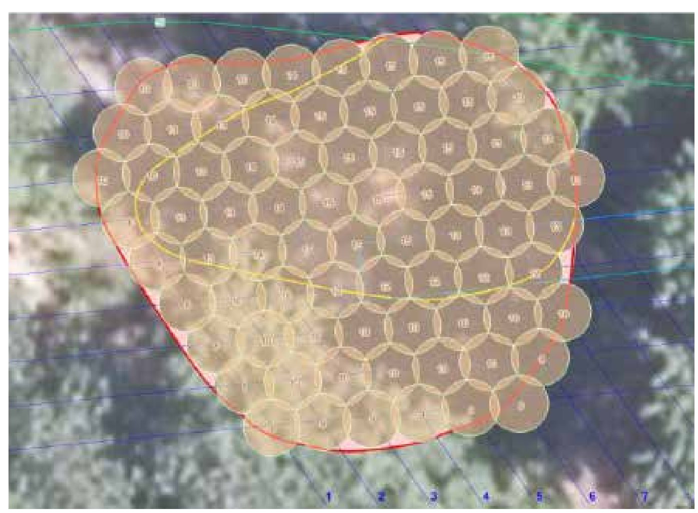

Figure 1. Layout of soil mixing columns with overlap

Figure 2. Mixing head with one level of flights designed to mix the soil *in situ*

Figure 3. Drill rig 100 ton RTG machine RS20.

Figure 4. Discharge capability along the auger flights to convey grout to mixing zone

Results

Post application monitoring of soils in the target area showed a reduction of between 40 to 60% in total hydrocarbon mass within the treated area. A significantly larger percent reduction was achieved in the more soluble, lower molecular weight fractions as intended. Benzene was reduced to below the detection limit, naphthalene was reduced by 80 to 85% and phenols were reduced by 99% in soil (Table 1), demonstrating that ISCO was effective for significantly reducing the more mobile fraction of the contamination.

Table 1. Contaminant mass reduction following ISCO-ISS

	Total Hydrocarbons	**Benzene**	**Naphthalene**	**Phenols**
Contaminant mass before ISCO-ISS (kg)	2,000-3,000	50-100	400-600	~10
Concentration after ISCO-ISS (mg/kg)	321	ND	23	0.04
Contaminant mass after ISCO-ISS (kg)	1,200	ND	85	0.1
Percent mass reduction	**40 – 60%**	**~100%**	**80-85%**	**~99%**

The geotechnical targets, hydraulic conductivity and unified compressive strength targets were partially met after 28 days of curing as outlined in Table 2. The results showed a direct correlation between the moisture content and the UCS; the samples that came back below the UCS criteria of 0.15 Mpa had an average water content of 32%. The pilot test showed that the samples continued to harden after 28 days as the blended soil continued to cure.

Table 2. Soil characteristics following ISCO-ISS

	Hydraulic Conductivity (K)	Unconfined Compressive Strength (UCS)
Goal:	< 1 X 10^{-6} cm/s	Minimum of 0.15 MPa with 90% ≥ 0.35 MPa
Result:	Average: 3.1 X 10^{-7} cm/s Range: 2.6 X 10^{-9} cm/s – 1.5 X 10^{-6} cm/s	22 samples ≥ 0.35 MPa; 29 samples ≥ 0.15 MPa; 6 samples did not meet the criteria
Comment:	13 of 14 samples met goal of K < 1 X 10^{-6} cm/s after 28 days	Direct correlation between UCS and water content → higher moisture content in non-compliant samples

Summary

The combined ISCO-ISS application at this site has several remedial goals. In terms of contaminant reduction, the field application outperformed what was observed in the bench scale, thus the field result was greater than expected. The remedial goal for hydraulic conductivity was met with only 1 of 14 samples having a hydraulic conductivity of greater than 10^{-6} cm/s with that one sample having a hydraulic conductivity of 1.5 x 10^{-6} cm/s. The desired remedial goal for compressive strength was not met as less than 90% of the samples had a UCS > 0.35 MPa. This result was closely correlated with the moisture content of those samples which was significantly higher in non-compliant samples. However, multiple lines of evidence including additional testing and field assessment demonstrated the ISCO-ISS remedy successfully attained the intent of the desired performance goal for strength and will avoid a long-term soft ground condition that would inhibit future use or development of the site.

Key Project Contacts

Lead Consultant:
Torben Højbjerg Jørgensen
Principal, Leading Specialist
COWI A/S
Vestre Stationsvej 7, Odense, Denmark
Phone: +45 56 40 48 69
Email: tjr@cowi.com
Website: www.cowi.dk

Technical / Design Support:
Christopher A. Robb, P.E.
Principal Engineer
Geosyntec Consultants, Inc.
Mequon, WI, USA
Phone: +1 262 834 0232
Email: crobb@geosyntec.com
Website: www.geosyntec.com

Soil Mixing Contractor:
Kim Rikard Jensen
Projektchef
ARKIL FUNDERING A/S
Mossvej 2A, Horsens, Denmark
Phone: +45 76 41 22 33
Email: krj@arkil.dk
Website: www.arkil.dk

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