Use of In-situ Soil Mixing as the delivery tool for Lime activated Sodium Persulphate for the in-situ chemical oxidation of chlorobenzene contamination.

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Churngold Remediation Limited (Churngold) were selected as a specialist remediation contractor for remediation works required on part of the former ICI Burnhall Facility, Thornton. This part of the Site is being developed as part of the Lancashire Waste Partnership PFI Project to enable the construction of an innovative green and brown waste composting facility. Churngold worked alongside RPS Planning & Development and Waste 2 Resources (W2R), the principal contractor for the project, in developing a remediation strategy for the Site.

Extensive Site Investigation works undertaken by RPS identified hotspots of elevated Chlorobenzene (MCB), all isomers of Dichlorobenzene (DCB), Trichloroethene (TCE) and Tetrachloroethene (PCE), which when combined totalled just over 0.7 hectares. The investigation data indicated that the contamination occurred within the saturated zone, both as Dense Non-Aqueous Phase Liquid (DNAPL) and dissolved phase contamination. A subsequent Detailed Quantitative Risk Assessment (DQRA) using ConSim determined that the Contaminants of Concern (COC's) posed an unacceptable risk to the environment. The key receptor at risk was a non-tidal ditch that forms the northern boundary of the Site.

Best assessment of the remediation options

Based on detailed discussions with the principal stakeholders (including Lancashire County Council, the Environment Agency, Wyre Borough Council, W2R, Bovis Lend Lease and Global Renewables) criteria were developed to determine the most appropriate remediation strategy. The key criteria were as follows:

- Capable of reducing contaminant concentrations below the remedial target concentration
- Will fit in with the timescales of the development programme
- Will not cause unacceptable issues during remediation such as nuisance, particularly contaminant odours
- Costs in keeping with the objectives of the remediation

A detailed review of remedial options was undertaken to assess what techniques could be applicable at the Site. Each option was assessed based on a simplified Site Characterisation Model, which was designed to highlight the difficulties faced by any attempt to treat the encountered contamination thus focusing the decision making process. The key considerations of the model were:

- Low permeability geology and low hydraulic groundwater flow;
- Heterogeneity of the geology;
- The physiochemical properties of the COCs;
- Concentrated pockets of contamination indicative of residual NAPL;
- Limited timeframe and logistical restrictions associated with the overall Site development;
- Scale of required treatment; and
- Depth and geometry of treatment zones.

Assessed technologies included Dual Phase Vacuum Extraction, In-situ Biological Techniques, Enhanced 'Pump and Treat', Ex-situ Methods and Reactive Barriers. Methods based on extraction/abstraction would be hampered by the low permeability geology and rate limiting release of gross contamination within the source zones. The engineering solution required to overcome these issues would be cost prohibitive. Other techniques were also ruled out on cost, timeframe and performance issues.

The most favourable technique, which was known to be very effective for the destruction (oxidation) of the COC's, was In-situ Chemical Oxidation (ISCO). ISCO however, relies on contact between the oxidant and contaminant to ensure destruction of the COC's. As contamination was partitioned within soil and as NAPL often in organically rich silt sand bands, conventional methods of injection would not provide sufficient certainty of this being achieved. An innovative method of delivery and selection of the most appropriate chemical oxidants was required to maximise the effectiveness of ISCO. The solution offered was based on an innovative combination of soil mixing and high strength oxidants, which would offer the following advantages:

- The addition of mechanical mixing together with conventional injection would increase the contact of oxidant and contaminant;

- The treatment intensity could be varied by altering the rate of mixing, the speed of advancing the mixing head, the oxidant injection rate and column spacing;
- The process would be rapid, capable of covering large treatment areas;
- It would avoid fixed infrastructure i.e. injection wells;
- It would be capable of targeting specific horizons within the subsurface, thereby minimising wastage of oxidant solution;
- It would not generate any waste streams or VOC emissions.

Represents best, rather than good or average practice

Churngold undertook detailed literature reviews, laboratory studies and a pilot study in order to optimise treatment design. The first stage involved the selection of the most appropriate chemical oxidant. A literature review determined that modified hydrogen peroxide and catalysed sodium persulphate (persulphate) were likely to be the most effective oxidants. Preliminary experimental results, using soil and groundwater samples collected from site, demonstrated that lime activated persulphate was the most effective oxidant, routinely reducing COC masses by >95% in each test microcosm. It was therefore agreed that work should advance to a site scale Pilot Study using this oxidant. The pilot study comprised the use of a modified Continual Flight Auger (CFA) linked to an oxidant mixing and injection system and confirmed that this type of delivery was effective with groundwater and soil contaminants being reduced by an average of 97% and 49% respectively.

With the concept proven, work began on refining the process. A further laboratory study concluded that the use of hydrogen peroxide based oxidants were not as effective as activated persulphate. A more detailed refinement of the activation of the persulphate helped improve the performance of the process. High ratios of hydrated lime and buffers were used to maintain a strongly alkaline pH, which was shown to be critical in extending the activation lifetime of the oxidant.

Addition of high strength lime slurries had several major benefits. The first was that their surfactant properties increased the surface area of NAPL available to the oxidant and added to the dissolution of the contaminant in the dissolved phase (where oxidant reactions are at their optimum). The excess of lime also helped to improve the geotechnical stability of the treated soils by reacting with any by-products, including free sulphate to form benign minerals such as gypsum.

Work was also undertaken to improve the CFA mixing rigs. This included modifications to the mixing heads and auger strings, inclusion of GPS, process control and data logging of all key operational parameters. The rigs also featured a number of modifications to improve health and safety, including better seals and splash guards.

Cost effectiveness and durability over the period of operation

Although extensive site characterisation was completed by RPS, it was agreed with them that additional information on the vertical distribution of the contamination was important. A Membrane Interface Probe (MIP) investigation was therefore undertaken by Churngold to help identify depths to contamination in the subsurface. The results of the survey were used to ensure the treatment was focussed and/or intensified at the most impacted depths, between 1.5 and 12.0 metres below ground level (mbgl).

The flexibility of the mixing and injection system (varying injection rates, ability to adjust column spacing, ability to inject at specific depths and ability to create chemical oxidant batches of varying concentrations) enabled Churngold to intensively target those areas which had been identified as heavily impacted without wasting valuable resources on those areas which were less impacted. Where results indicated the presence of NAPL the injection programme was modified to allow for two rounds of treatment. This was one of the keys to the success of the project as very little oxidant was wasted, making the process highly efficient and cost effective.

Significant reduction of pollution burden rather than transferring it

Baseline mass balance calculations estimated that approximately 17,400 kg of contamination was partitioned in soil and NAPL, with a further 210 kg in groundwater. Calculations completed post remediation indicated that 11,715 kg of contamination was destroyed in-situ as part of the process. Philip Block, the technical manager for FMC who hold the worldwide patent on the use of persulphate for remediation purposes, suggests '*…that this is one of the largest, if not largest, destruction of contamination at any site using persulphate oxidation*'.

Application of in situ chemical oxidation using this method prevented approximately 48,400 tonnes of contaminated from soil being sent to landfill. Table 1 summarises some of the key parameters from the operational phase.

Hotspot	Area Requiring Treatment (m^2)	Total No. of Columns	Mass of Injected Oxidant Solution (kg)
A	3,974	1,438	106,921
B	194	139	13,810
C	1,080	946	146,306
D	624	238	10,101
E	1,446	113	4,937
Total	**7,318**	**2,874**	**282,077**

Table 1. Treatment Areas and Oxidant Injection Masses

Compliance with Health and Safety

Robust health and safety practices were put in place and policed by W2R throughout the works. All operatives involved in the mixing process who could come into contact with the oxidants wore full chemical, suits, full face masks and long gloves in accordance with the PPE requirements identified as part of the risk assessment process. Regular toolbox talks were undertaken and all personnel involved in the process were fully inducted. Operations were run in accordance with detailed method statements and designed to ensure safe operation. Consideration of health and safety was also a determining factor in the selection of persulphate, which is less hazardous to store and handle when compared to other oxidants such as hydrogen peroxide.

Community and stakeholder acceptance

In-situ remediation techniques were promoted by the regulators as a way of managing the potential risks and nuisance that could have been presented by ex-situ methodologies. The injection of the chemical oxidant over a single round or minimum number of rounds of injection was also a key design aim to reduce the treatment timeframes.

The use of alternative techniques employing extraction/abstraction would have meant extending the remediation to several years and presented potential long- term nuisance within the local environs, thus not meeting the requirements of W2R in terms of delivery of their PFI scheme. Similarly the use of barriers would have resulted in a long-term solution due to the slow travel of groundwater in the impacted zone and hence would not have satisfied the long term liability issues of Lancashire County Council who would ultimately take back ownership of the site back including any latent environmental liability. The techniques would also have required maintenance and on-going monitoring. The solution addressed all parties' requirements.

Throughout the project the regulators and client were regularly engaged with updates, including several on-site presentations to interested parties involved in the project. Stuart McDonald, overseeing the project for the Environment Agency, concluded the following within his site sign-off correspondence: '*In reviewing all available documents, I am satisfied that the remediation scheme has resulted in a massive reduction in the bulk contamination at the defined 'hotspots', and I consider this process to be particularly successful, as demonstrated in your validation reports…I would like to take this opportunity to thank RPS, Churngold and W2R for all the assistance given during this period of the remediation. It is this that has enabled us to have considerable faith in both remediation methods employed and the validation of results.*'

Considerations of Sustainability (including the wider stakeholder impacts on and off site)

Remediation works took place in order prevent contamination impacting on the "Non-Tidal Ditch" running to the north of the site. It has been estimated that in total 11,493 kg of chlorobenzene and dichlorobenzene isomer contamination was destroyed by ISCO within both soil and groundwater. Destruction of this contamination has potentially prevented an estimated 7,183,125 m^3 of water in the Non-Tidal Ditch from becoming impacted beyond Environmental Quality Standards.

The Non-Tidal Ditch was sampled in three locations before and throughout the works in order to assess the impacts of the remediation process on the ditch. Average contaminant concentrations pre and post works are provided in Table 2.

	Average concentration of chlorobenzene and dichlorobenzene isomers (mg/l)	
Sample Location	**Sept – Nov 2007**	**Feb – March 2008**
1 (upstream)	1.0	0.1
2 (midstream)	1.9	0.1
3 (downstream)	1.9	0.04

Table 2: Average concentrations of chlorobenzene and dichlorobenzene isomers within water samples taken from 3 locations within the Non-Tidal Ditch during two different time periods.

Results from water samples taken from the surface water feature show that concentrations of chlorobenzene and dichlorobenzene isomers have reduced more than ten fold since completion of the ISCO treatment.

Genuine Novelty

Traditional chemical oxidation delivery and its effectiveness is limited by a number of factors including:

- Works best in permeable homogeneous geologies
- Limits mass of oxidant that can be delivered
- Does not guarantee oxidiser/contaminant contact
- Treatment duration may extend due to multiple rounds of treatment due to difficulty of injection and achieving dispersion into the treatment zone

The use of soil mixing negated each of these concerns. Despite the impermeable, highly heterogeneous geology, remedial targets were achieved within 80% of the injected footprint after only one round of injection. All works were completed within the 20 week strict timeframe.

To our knowledge the innovative combination of soil mixing and use of an emerging oxidant, selected and developed to overcome a series of site-specific restrictions, has not been used in the UK or European markets before and therefore should be considered novel. The unique use of high strength lime activators aided the process by making more contamination available for oxidation adding to the innovative nature of the solution. Phil Block has confirmed that this project is the second largest application of persulphate to be undertaken worldwide. The largest, which is currently being undertaken in Texas, is using a similar soil mixing delivery technique.

Figure 1: CFA Rigs In full swing

The work represents a significant technological advance for the industry, with the opportunity for widespread application

Until the design of this soil mixing technique, traditional ISCO was limited in its application by geological setting and cost of trying to achieve dispersion of sufficient oxidant into the sub-strata in order to affect contaminant breakdown without having to apply further expensive rounds of chemical injection. For oxidisable organic contaminant compounds, delivering chemical oxidants to the subsurface via in situ soil mixing is an excellent way of simultaneously destroying contaminant mass in both the soil or free phase source area and within dissolved phase. Remediation can be carried out to an extremely high standard within a reduced timeframe compared to traditional ISCO injection techniques and other technologies, which is a considerable advantage for projects which require short clean up times to meet development requirements. An overriding advantage of this technique however, is that is has been proven successful for use in challenging geological and hydrogeological environments and is flexible enough to be able to specifically target locally impacted areas within hotspots meaning that the chemical costs can be reduced. The many benefits of this novel technique certainly make it a viable option for increased application throughout the industry as a whole and will help promote more widespread uptake of ISCO technology.