# LAYMEN'S REPORT - VOPAK-EXPERO3 - LIFE09 ENV/BE/000407

## Soil remediation of ISCO with perozone® on an explosion-sensitive industrial site

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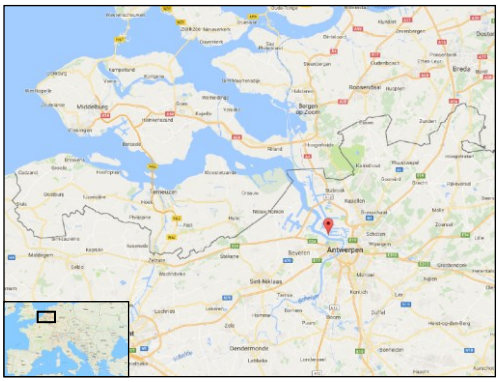
On the site of VOPAK Terminal ACS, in the port of Antwerp, a complex soil remediation is in progress.

VOPAK Terminal ACS is specialized in storage and transport of chemicals. The activities began around 1970. In the past, there were hardly any soil protection measures. In the 1990s, pollution caused environmental awareness throughout Flanders. Many sites in Antwerp today are struggling with historical soil pollutions. After several studies from the mid-1990s, a complex soil and groundwater contamination was identified for the site of VOPAK Terminal ACS. The remediation started in 2012.

**Figure: Location of VOPAK Terminal ACS**




**Support from the European Commission**

The historical contamination consists of a mixture of oils, aromatics and chlorinated solvents in groundwater. When designing the plan of redevelopment, it was soon found that different sequential remediation techniques would be necessary. VOPAK, advised by experts in this area, choose for the so-called in-situ chemical oxidation (ISCO). This technique is based on the injection of products in groundwater to break down the pollution through a chemical reaction. The injection product, perozone®, came into view: a mixture of liquid hydrogen peroxide and gaseous ozone.

The use of this reactive mixture on an operational chemical industrial site, where highly flammable products are stored, is therefore very innovative. The implementation is accompanied by numerous safety measures and guidance from various external experts. The European Commission's Directorate-General for Environment was prepared to support this challenging project financially through its LIFE + program. The VOPAK-EXPERO3 project was born and started in September 2010. Partners for this project are Badeco (safety coordinator) and RSK Benelux bvba (soil remediation expert). The remediation works are carried out by Verhoeve Milieu & Water, a remediation contractor specialized in this patented remediation technique[i].

**Project objectives of the LIFE+ project**

The main demonstration purpose of the project is the application of ISCO in chemical plants or storage areas that are in full operation and therefore have very high risks mainly toward safety (explosion risk). This has not previously been demonstrated in this circumstances.

The main targets of the project will be:

- Demonstrate the application of ISCO with perozone for the full scale remediation of a soil and groundwater contamination consisting of a cocktail of different organic components in very high concentrations.
- Develop an extensive health and safety plan defining the necessary safety measures for the use of the technique at explosion sensitive sites.
- Develop working procedures for implementation of the technique.
- Demonstrate the advantages (less carbon emission, more time-, cost- and energy efficient) of the technique in comparison with traditional remediation techniques.
- Evaluate the remediation technique in terms of viability and economical and environmental feasibility
- Dissemination of knowledge gathered in this project to target groups and stakeholders.

**Start of full-scale remediation works**

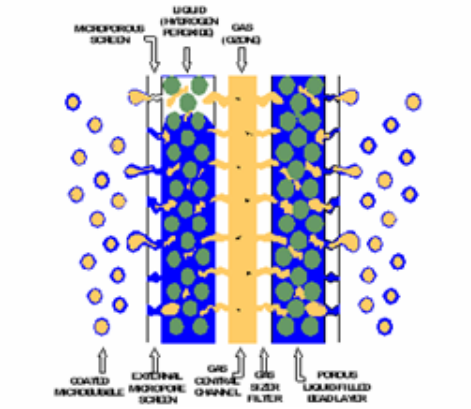
The soil remediation works were carried out in the period 2012 - 2017. They started excavating the source zone in November 2012 at the central access road of the chemical storage site. 460 tons of highly contaminated soil was removed and thermally treated. Subsequently, the installation of the ISCO injection system was started. In addition to the installation of 61 special injection filters, 38 vertical multi-phase extraction filters and more than 500 m of shallow vapour drains were installed. As a result, remediation can be carried out by in-situ chemical oxidation using perozone® and by multi-phase extraction.

**Figure: excavation at the central road**

**Innovative injection of perozone® in combination with soil vapour extraction**

For the perozone injection, ozone gas and liquid hydrogen peroxide should be present. Ozone gas can be extracted from the air using an ozone generator. However, hydrogen peroxide must be supplied. The gas and liquid injection mixes just before injection into the soil using specially designed injection filters. The ozone gas is pushed out of the filter via micro pores. In this manner, microbubbles coated with hydrogen peroxide are formed, as shown in the figure below.

**Figure: formation of coated microbubbles**



Ozone gas is highly reactive and degrades non-selectively organic material such as contamination and natural organic substances in the soil. The contaminants break into harmless products like $CO_2$ and water. We can assume that approximately 0.5 to 1.5 kg of ozone can break up to 1 kg of contamination. The amount of degraded contamination is directly related to the amount of ozone injected. Hydrogen peroxide makes soil contaminants detach from the soil matrix so they can be treated better with ozone gas.

In a first phase (March-November 2013), this in-situ remediation at the former drum storage area went flawlessly. In a second phase at the central access road, ozone and volatile hydrocarbons were sparged above groundwater and observed in concrete bursts and sewers potentially creating safety issues. It was decided to fine tune the perozone injection. The optimised injection rates resulted in low emissions of ozone and volatile compounds as controlled by safety measurements. The intensive follow-up program of safety measurements is a combined effort of VOPAK, RSK and Verhoeve.

A gas mixture of ozone and volatile hydrocarbons is explosive and must be avoided at all times. Therefore, the application of the perozone injection should always be combined with a soil air extraction. As a result, explosive mixtures cannot accumulate in the subsurface or migrate to the atmosphere. For the same reason, the concrete of a part of the central road was renewed in the first half of 2014, so that the soil air extraction could be more efficient and no emissions would occur.

**Remediation in explosion-sensitive industrial zones**

This LIFE+ project have shown that the ISCO with perozone can be carried out in explosion-sensitive areas of the VOPAK terminal. The safety parameters were monitored intensively according to the motto: by measuring we know. 171 safety controls have been carried out. When the action values were exceeded, immediate action was taken. Fortunately, this was rarely necessary once the optimal perozone injection regime was applied. Soil air extraction remains an essential part of the perozone injection controlling the safety risks.

**Figure: explosion sensitive zone**

**Remediation results**

At the core of the contamination, also known as the source zone, pure product is present in the pores of the soil. A large part of the contamination absorbs to the soil or dissolves in groundwater. Oils make up most of the contamination. Due to the non-selective nature of perozone® degradation, the oils are mainly degraded. Groundwater concentrations of these oils have declined over the course of the project, while those of chlorinated solvents remain nearly unchanged. After 3 years of perozone® injection, a significant amount of residual contamination remain. We expect because of the limited perozone® injection that the remediation of the source zone will still take a long time. This makes the economic feasibility of this remediation strategy in the source zone doubtful. Multi-phase extraction is considered as an alternative to remove at initial stage the bulk of contamination in the source zone.

Contaminants are spreading in the groundwater from the source zone to the plume zones. The estimates of the residual pollution and the experience in this LIFE project show that the remediation period is limited to several months or years in these plume zones. The remediation of these plume zones is both technically and economically feasible using ISCO with perozone®.

**Dissemination of knowledge**

The project team participated at two international conferences in order to disseminate the gathered knowledge in this LIFE project. Stakeholders were regularly informed via newsletters, progress reports for the authorities or publications in annual reports. Through the project website, technical project documents (final health & safety plan, procedures), conference presentations and poster, feasibility and validation studies of ISCO remediation strategy against traditional technologies were made available. This website will be updated with the new project results in the coming years.

**Figure: dissemination of knowledge**


**General conclusion**

ISCO with perozone® can be safely carried out in explosion-sensitive industrial areas, on condition that the remediation is accompanied by soil vapour extraction and an intensive safety monitoring program.

However, ISCO with perozone® is not a stand-alone strategy for contaminated areas with a cocktail of high concentrations of pollutants in the source zones, such as at the VOPAK site. Remediation in the zones should start with other remediation technologies such as multi-phase extraction. Unlike other remediation techniques, ISCO with perozone® produces hardly any waste and does not emit nearly any pollution to other environmental compartments. Due to a low remediation cost, this remediation technique is applicable under certain conditions, mainly in plume zones as demonstrated during the LIFE project.

[i] Kerfoot Technologies