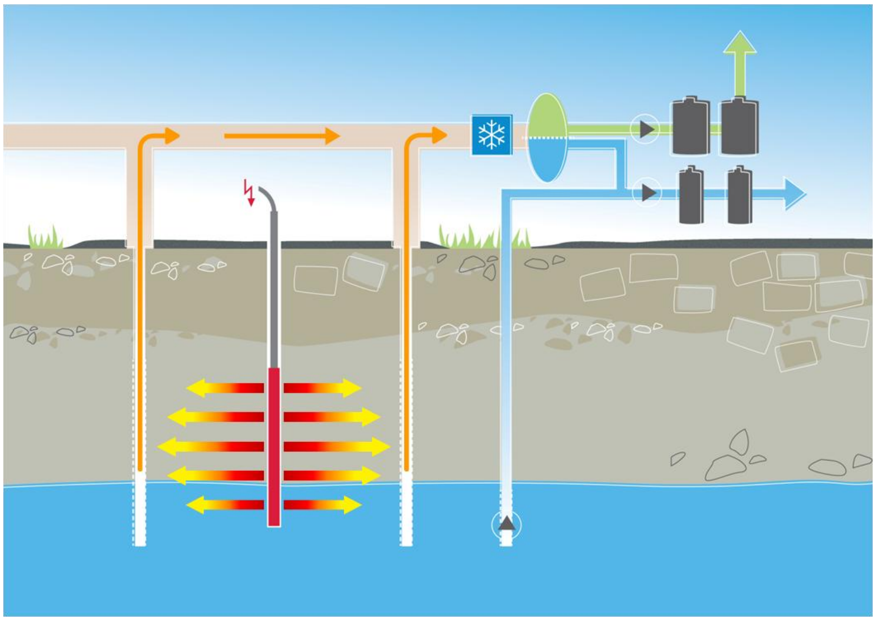
In situ thermal remediation of contaminated sites

A technique for the remediation of source zones



Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

INTERREG IVB

Summary

In situ thermal remediation (ISTR) is a technique for source remediation of organic compounds. It refers to the application of heat to the subsurface by various methods. Indepentent of the heating method the focus of ISTR is to mitigate source zone contamination by vaporising the contaminants due to sub-surface heating and extraction of the gas mixture from the sub-surface by soil vapour extraction (SVE). For the typical organic contaminations (density smaller and higher than water (LNAPL, DNAPL, in the context of CityChlor VOC = DNAPL) it is necessary to heat the sub-surface to 50°C to 100°C. In very special cases - at higher temperatures (above 120°C) - a contaminant destruction can be achieved. The extracted contaminated and partial hot soil gas mixture has to be subsequently cooled and treated by air treatment systems like activated carbon filters or catalytic oxidation (CatOx). In situ thermal remediation techniques have their advantages which make them ideally suited for the application in build up urban areas. Nevertheless, certain risks can occur and should be adressed by a proper engineering.

Table of content

List of Abbreviations

BTEX	Benzene, toluene, ethylbenzene, and xylene
CatOx	Catalytic oxidation
CHC	Chlorinated Hydrocarbons
DNAPL	Dense nonaqueous-phase liquid
GW	Groundwater
ISTD	In situ thermal desorption
ISTR	In situ thermal remediation
LNAPL	Light nonaqueous-phase liquid
NAPL	Nonaqueous-phase liquid
PCE	Tetrachloroethene
TCH	Thermal conductive heating
SAI	Steam air injection
SEE	steam enhanced extraction
ERH	Electric resistance heating
RFH	Radio frequency heating
TCE	Trichloroethene
TPH	total petroleum hydrocarbon
VOC	Volatile organic compounds

1 Introduction

1.1 CityChlor and the integrated approach

Space is scarce in Europe. Even in the subsurface it is getting busier. Large-scale soil and groundwater contamination with chlorinated solvents are often an obstruction for urban developments. The traditional way of dealing with polluted soil and groundwater does not work in all cases and is not economically and sustainable feasible. In urban environments multiple contaminations with chlorinated solvents are often mixed with each other and spread underneath buildings. This not only leads to technical problems for remediation, but also to liability and financial discussions and hence has an impact on society. An integrated approach and area-oriented approach is needed to tackle the problems. The CityChlor project has demonstrated that remediation and sustainable development can evolve on a parallel timescale.

An integrated approach combines all aspects that are relevant to tackle the problems that pollution with VOC in urban environment causes. Depending on area, site and context different aspects together or parallel to each other can be used. Not only technical solutions are included, but also socio-economical aspects as urban development, communication, financial and legal aspects, time, space, environment and actors (active & passive) have to be handled.

CityChlor did not remain at single case remediation, but looked at the area as a whole in a bigger context: the area-oriented approach. A technical approach that makes it possible to remediate, monitor and control multiple groundwater sources and plumes within a fixed area.

1.2 CityChlor and technical innovations

The managing of knowledge and technical innovations are one of the key to achieve a sustainable city development. A development project has to cope with loads of information coming from different disciplines in different (technical) languages and with different uncertainties. With chlorinated solvents, the knowledge about the pollution will always have a certain uncertainty that can have an impact on the course and the costs of the remediation. An efficient 'managing of knowledge' will try to decrease this degree of uncertainty.

CityChlor therefore also worked on the technical aspects of characterization and remediation. The conventional techniques that are applied for investigation and remediation have their limitations dealing with chlorinated solvents. Promising innovative techniques exist, but do not easily find their way to current application. This barrier is often caused by lack of knowledge on different levels. Experts and contractors do not always have the means to invest in experiments with new techniques, authorities are reluctant to accept techniques of which the results may be uncertain and clients aren't eager to pay for experimental techniques.

Dissemination of knowledge can break this deadlock. CityChlor therefore collected experiences from field application of innovative techniques and implemented itself a number of techniques in pilot projects. For the detailed outcomes, the reader is referred to the specific reports.

CityChlor - “new solutions for complex pollutions” **http://www.citychlor.eu/**

2 Aim of this Study

Remediation of sources of environmental pollutions with chlorinated solvents is a challenging task. Although lots of remediation techniques for these kinds of contaminations are available, there are still too many cases which can not be handled with widely used methods. For example, soil vapor extraction is improperly for remediation of dense soil layers or non-aqueous phase liquids (NAPLs). In urban areas dig and dump may be impossible due to buildings above the source of pollution. In the densely populated Northwest Europe, the pollution today is often situated under building or residential areas and therefore hardly accessible. In situ thermal remediation techniques seem to offer a solution. They have several crucial advantages that make them ideally suited for the application in urban environments. For some sources the thermal in situ remediation is an adequate solution to clean up the soil. Nevertheless risks for implementation are existing, depending on site specific conditions.

This study gives an introduction on in situ thermal remedition techniques and shows data of already performed remediations in Europe. It was elaborated in the course of a pilot application of an in situ thermal remediation in Stuttgart, on the search for cases conducted under similar conditions. It informs interested parties about the variety of the practical experiences and encourages them to think about a thermal solution for a “chlorinated pollution”. As technology overview documents and implementation guidelines can serve HIESTER *et al*., 2013; JOHNSON *et al*., 2009 and U.S.A.C.E., 2009. Even as the above mentioned guidelines give more details on the different techniques, their fields of application and their limitations, the information only serves as a starting point for identifying options for chlorinated solvent remediation. However, decisions about the use of a particular technology will depend on site-specific factors and may require treatability studies (pilot test).

3 In situ thermal remediation:

Basics and fields of application

In situ thermal remediation (ISTR) refers to the application of heat to the subsurface by various methods. Indepent of the heating method the general aim of temperature rising in the treatment zones is to increase mobility of contaminats and/or a contaminant destruction.

In more details, volatile, semi-volatile and non-volatile organic contaminants in the soil are mainly vaporized or in some very special situations even destroyed. The main physical mechanisms are evaporation and steam distillation, but even oxidation and pyrolysis (chemical decomposition in the absence of oxygen) can occur. In most cases contaminants are vaporised (as it is with chorinated solvents) and extracted via the soil gas by a soil vapour extraction system (SVE).

Techniques that base solely on the transport of fluids to deliver reagents or to remove dissolved contaminants are dependent on (amongst other factors) the permeability of soil and their distribution in or around the contaminated soil volume. As permeability of the natural subsurface (subsoil and aquifers) varies over some orders of magnitude the emission of contaminants from low permeable zones into high(er) permeability zones, where the air and groundwater flow takes place, is limited by the diffusion. Moreover the ability to deliver reagents and / or additives to transform or to remove contaminants are only possible in the high permeable zones, whereas the contaminants unfortunately are mainly accumulated in the low permeable zones. The effectiveness of heat to remove contaminants depends mostly in the more uniform conduction of the “reagent” heat. In most soil materials, thermal conductivities range over less than one order of magnitude. Hence the relatively small range of thermal conductivities leads to a more or less uniform heating and subsequent treatment within a contaminated zone.

Figure 1 shows the general conception of TCH application, consisting of heating elements, monitoring elements for pressure and temperature, as well as soil vapor extraction wells in the treatment area. The facilities for cooling and cleaning of soil vapor condensat and the treatment of pumped groundwater are located outside the treatment area.

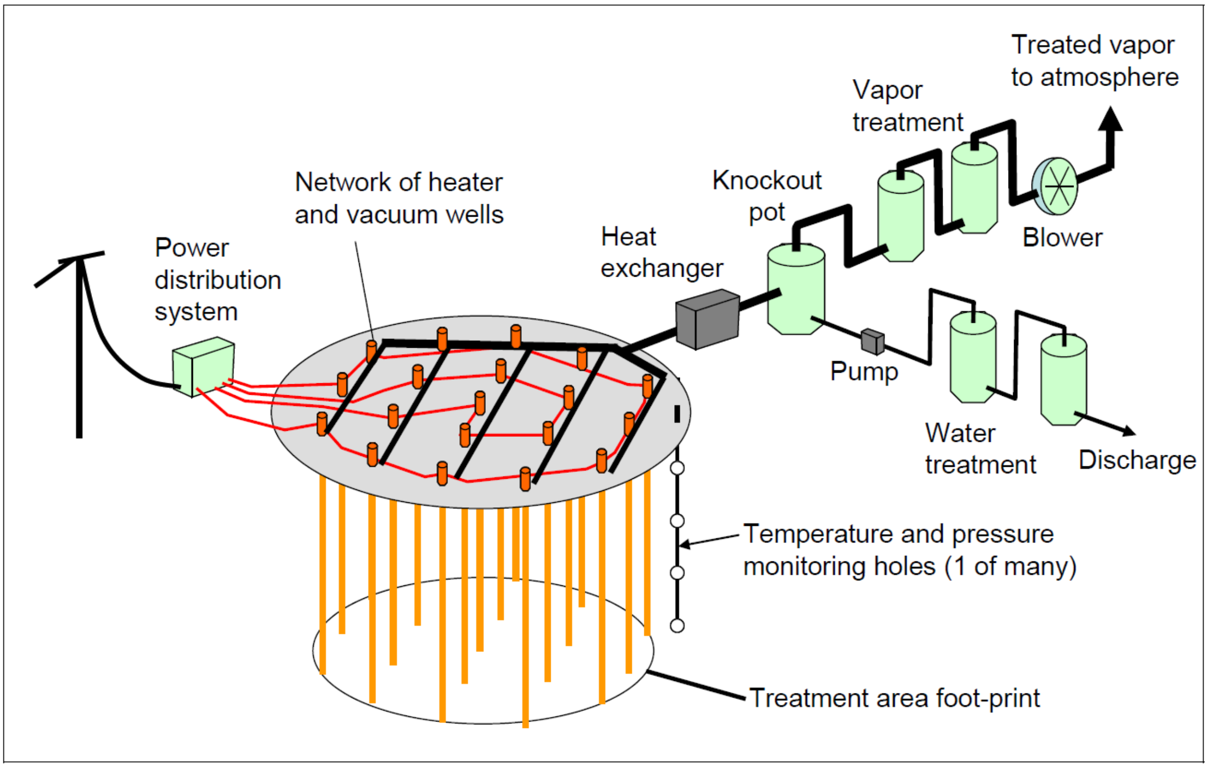


Figure 1: Conceptual design of a thermal conduction heating application (HERON and BAKER 2009)

As with other remediation technologies there is a bunch of names and methods, as different technology vendors are in this market and offer their techniques under specific names. Despite the differences between the techniques and the offering companies three general heating methods can be distinguished.

1. **Thermal conductive heating (TCH),** also known as in situ thermal desorption (ISTD): heat is transferred by conduction from so called thermal wells into the subsoil. Heater wells are either heated by electricity or circulating hot gas (Figure 2).

2. **Steam air injection (SAI)** or steam enhanced extraction (SEE): heat is transferred convective via steam and hot air into the subsoil (Figure 4)

3. **Electric resistance heating (ERH)** and Radio frequency heating (RFH): heat is created directly in the soil

Whereas for 1.) and 3.) the structure of the soil matrix is less important, for 2.) a good or medium permeability of the soil is necessary (gravel, sand or coarse silt) to inject the steam air mixture and to achieve an effective “steam flow” to heat up the source zone. On the other hand for 2) the specific energy input us much higher than for 1.) and 3.). As illustrated in Figure 4 small layers or lenses of dense soil material can be heated by a steam injection underneath.

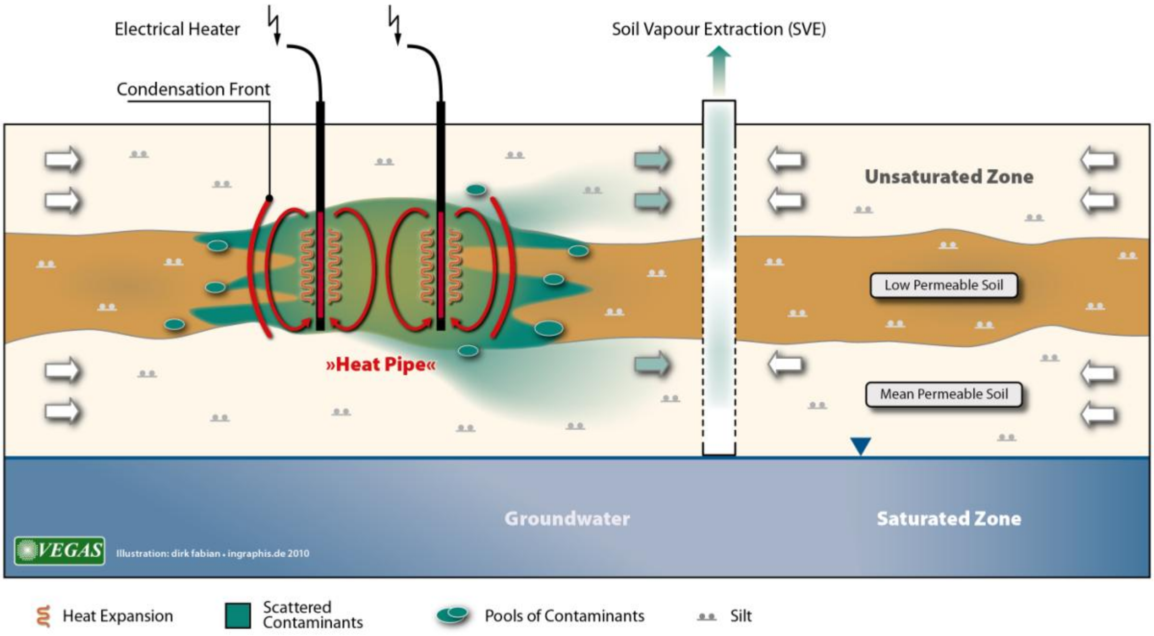
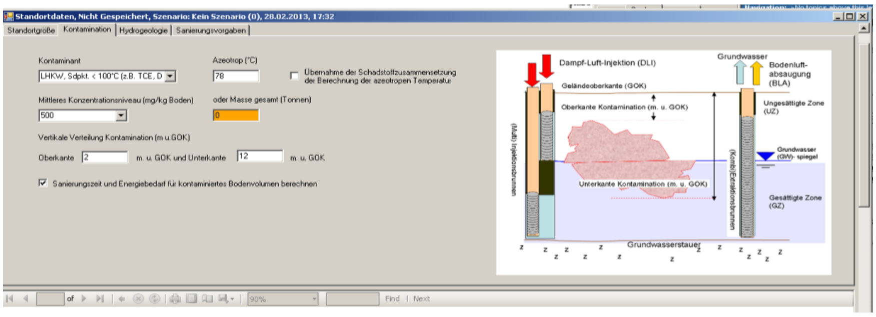


Figure 2: Principle of thermal conductive heating (TCH) (VEGAS 2010)

For the preliminary design of a SAI application a software tool was devoloped by VEGAS (2012) and is available as free download. Key data about the site, the contamination, hydrogeology and remediation specifications are compiled with the help of input masks (see Figure 3. The tool enables a quick pre-planning of the remediation process, the field equipment (injection- and monitoring wells, …) and the installation engineering.



Kontaminant: LHKW, Sdpkt. < 100°C (z.B. TCE, D

Azeotrop (°C): 78

☐ Übernahme der Schadstoffzusammensetzung der Berechnung der azeotropen Temperatur

Mittleres Konzentrationsniveau (mg/kg Boden): 500

oder Masse gesamt (Tonnen): 0

Vertikale Verteilung Kontamination (m u.GOK)

Oberkante 2 m. u. GOK und Unterkante 12 m. u. GOK

☑ Sanierungszeit und Energiebedarf für kontaminiertes Bodenvolumen berechnen

Figure 3: Software Tool for design of an steam air injection (VEGAS 2012)

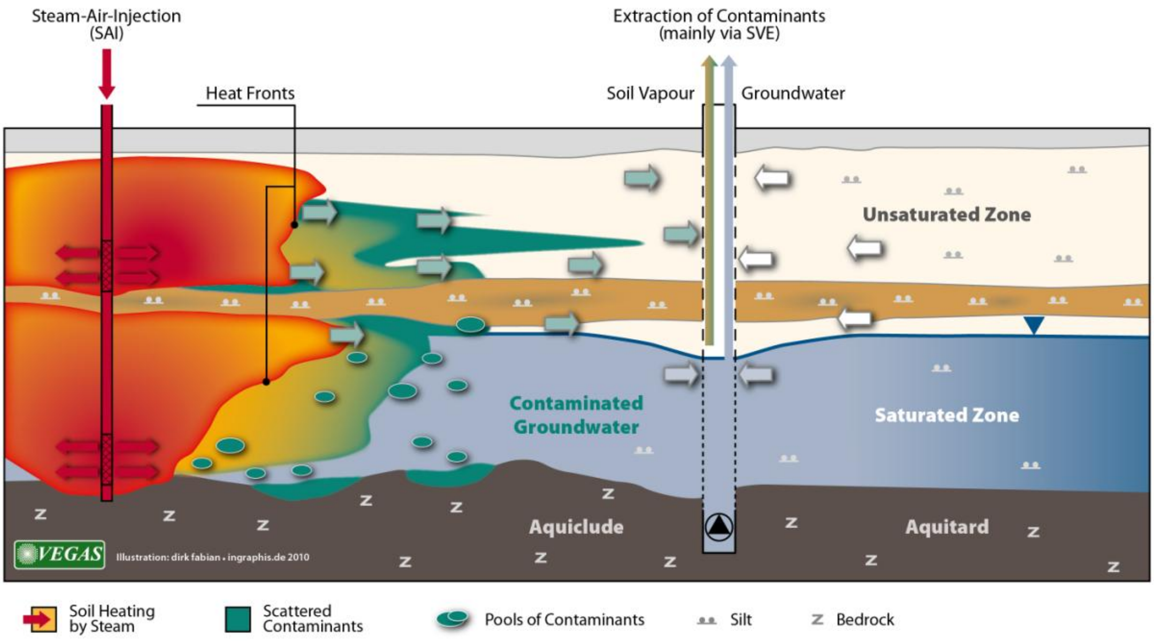


Figure 4: Steam air injection in the saturated and unsaturated zone (VEGAS, 2010)

Especially for complex hydrogeological conditions with different layers (e.g, clay and gravel or sand layers, saturated zone) a combination of different techniques may be necessary to reach the remediation targets in an efficient way. The economical and effective delivery of heat into the subsurface is the main success factor for a thermal treatment. As Table 1 shows, each technique has a different maximum temperature level. For the remediation of chlorinated solvents all techniques can reach the necessary temperature level according to site properties and facility design. Only some of the CHCs have a boiling point below 100°C, but even the compounds with a boiling point above 100°C can be easily vaporised together with water. The reason is, that the boiling point of a mixture of NAPL and water is lower than each of the boiling points of its compounds. This so called co-distillation (azeotropic) point for all CHCs is below 100°C and can therefore be reached by all of the ISTR methods.

Table 1: Maximum Temparatures of ISTR-techniques (U.S.A.C.E. 2009)

Technology	Maximum Temparture
Thermal conductive heating	750 – 800 °C
Steam air injection	170 °C
Electric resistance heating	100°C
Radio frequency heating	300-400°C

Common with all heating methods is the removal of the contaminated gas via soil vapor extraction applying an underpressure. Due to the increased mobility of contaminants also the groundwater maybe affected by DNAPLs or solved contaminants. Groundwater should then be extracted by recovery wells or dual phase extraction wells to prevent further spreading.

General Advantages of in situ thermal remediation techniques

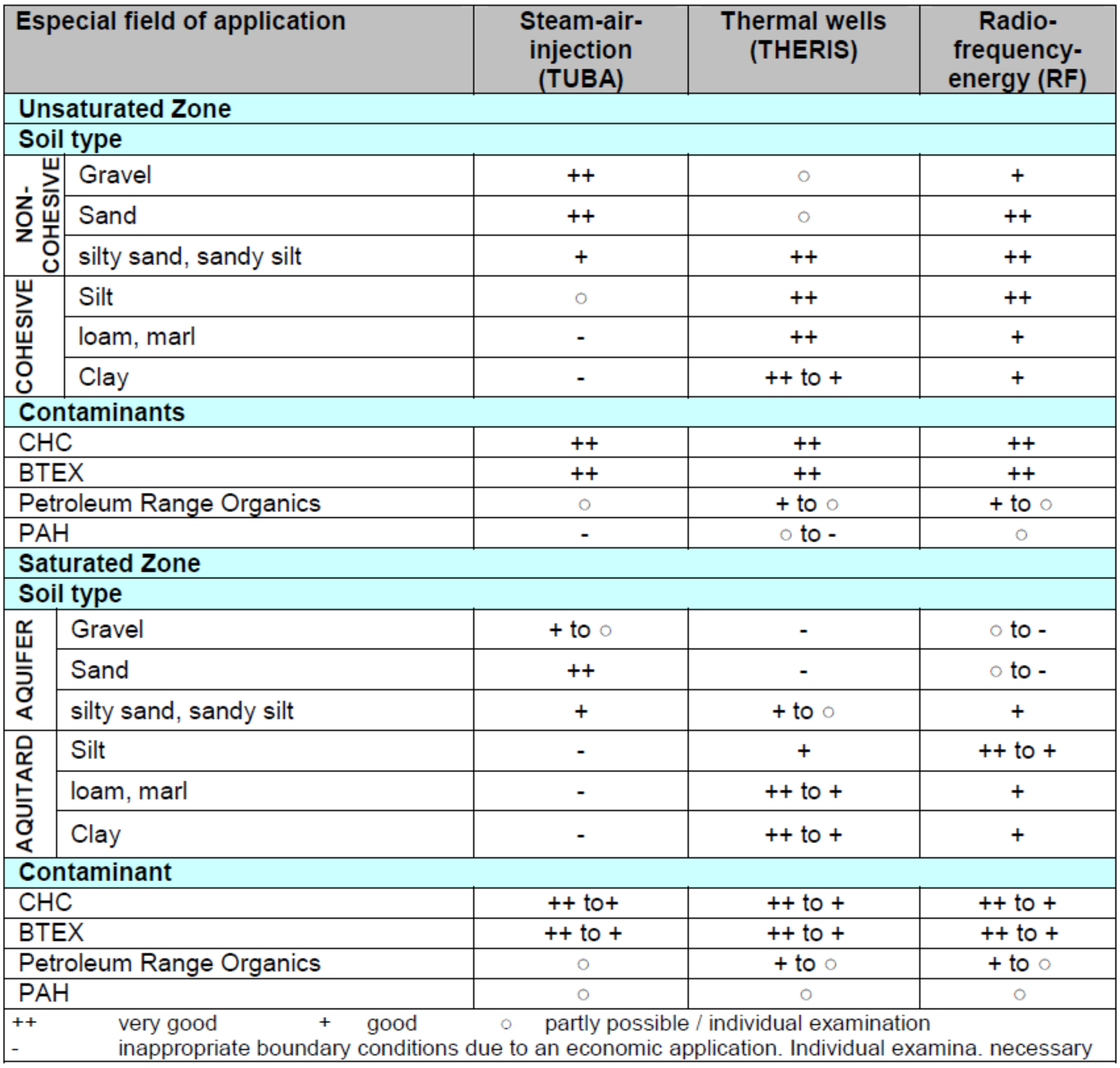
- Short remediation time of a few months, maximum between one or two years
- Treatment of non-aqueous phase liquids (NAPLs) possible
- Less sensitive to heterogenous or dense subsoil
- No excavation and transport of soil necessary
- Implementation below buildings possible (check risk of soil shrinking first)
- Very low remediation targets can be reached for soil

Limitations of in situ thermal remediation techniques

- No treatment of inorganic contaminants (probable exception of volatile metals such as mercury).
- Some of the ISTR methods may not be appropriate for remediation of very low volatility organics, such as pesticides, some PAHs, dioxins, and PCBs.
- Site conditions that may not be conducive to ISTR include high groundwater fluxes, buried ordnance or presence of critical subsurface facilities or utilities.
- High remediation costs in a short timeframe
- If the size of the treatment volume is large, the cost of ISTR may also be considered a "limitation" depending on financial resources.
- Soil shrinking can occur under certain conditions (clay soils and soils with high content of organic matter) which could exclude ISTR near or under buildings.
- Risk for indoor air pollution can occur during implementation under or besides builings.
- The techniques have a relatively high demand for engineering in the planning phase and a high need for monitoring and supervision in a short implementation phase.

In situ thermal remediation techniques have their advantages which make them ideally suited for the application in build up urban areas. Nevertheless, soil shrinking should be considered under certain geological conditions, for example with clay soils and soils with high content of organic matter (lab tests necessary). Clay soils may shrink due to desiccation. Organic materials degrade due to heat and are causing a loss in volume and settlement. Risk of soil shrinking and settlement is not an issue in non-built-up areas, but in urban areas it can be a criterion for exclusion of ISTR. Table 2 shows the field of application for the different thermal techniques. In general, the field of application for steam-air-injection are non-cohesive soil types, whereas conductive heating (thermal wells) has it´s field in dense soils like silt, loam and clay. Radiofrequency has the widest field of application related to the soil types. However an individual appraisal for each site is necessary. Especially for complex hydrogeological conditions with different layers (e.g, clay and gravel or sand layers) a combination of different techniques may be necessary.

Table 2: Fields of application of in situ thermal remediation (from HIESTER et al 2013)



Especial field of application		Steam-air-injection (TUBA)	Thermal wells (THERIS)	Radio-frequency-energy (RF)
Unsaturated Zone				
Soil type				
NON-COHESIVE	Gravel	++	○	+
	Sand	++	○	++
	silty sand, sandy silt	+	++	++
COHESIVE	Silt	○	++	++
	loam, marl	-	++	+
	Clay	-	++ to +	+
Contaminants				
CHC		++	++	++
BTEX		++	++	++
Petroleum Range Organics		○	+ to ○	+ to ○
PAH		-	○ to -	○
Saturated Zone				
Soil type				
AQUIFER	Gravel	+ to ○	-	○ to -
	Sand	++	-	○ to -
	silty sand, sandy silt	+	+ to ○	+
AQUITARD	Silt	-	+	++ to +
	loam, marl	-	++ to +	+
	Clay	-	++ to +	+
Contaminant				
CHC		++ to+	++ to +	++ to +
BTEX		++ to +	++ to +	++ to +
Petroleum Range Organics		○	+ to ○	+ to ○
PAH		○	○	○

++ very good + good ○ partly possible / individual examination
- inappropriate boundary conditions due to an economic application. Individual examina. necessary

4 Comparison of various pilot applications

For the overview of application of the ISTR in Europe a research was made to get an overview about the application of these techniques. In fact there are not so many apllications yet in Europe, although lots of scientific research has been made. What is the reason for this? In general it happens with every new technique: vendors are enthusiastic and customers are sceptic. Interested parties want to have verification of technical reliability, they are not sure about political and social acceptance and financial risks of new techniques. They want to have certainity about achievable goals and evaluation criteria. Sharing of knowledge is one solution to overcome these obstacles for new techniques. This overview wants to help in this way.

Costumers want to see a prove about the technique:Is it working? What are the costs? Is it cost effective? What if it fails? What are the alternatives? In-situ thermal remediation competes against traditional, proven methodes like dig & dump and pump & treat as well as against other innovative remedtiation methods like in-situ chemical oxidation (ISCO) or other biological methods. The method of in-situ thermal remediation is not the solution for all difficult contaminations, but for some cases it is the onliest method to deal with a contamination. The challenge is to find out the cases where a in situ thermal remediation is the optimal method for site remediation, balancing the pros and cons regarding the site conditions.

For this overview an internet research was made to find out about the use of ISTR in Europe. Sources for information were homepage of vendors, direct information from companies, conference proceedings and other publications. Indepent publications from clients or scientific articles with detailed information of examples have been quite rare but now more and more examples have been published, for example Woisnitza et al. 2011, Held 2012, Denzel et al 2011. The compilation was done in preparation of a european-wide tender of a pilot test in Stuttgart (Landeshauptstadt Stuttgart 2013) In fact tendering documents were not only asked by technology vendors, but also by consultants. Effectively the number of real technology vendors is estimated to 8 to 10 companies in North-West-Europe. The data of the compiled applications can be found in **Table** 3.

Comparing the listed cases different data quality has to be considered. As often, failed projects are not published to avoid bad reputation or to cloud mistakes in the preperation or implementation of the remediation. Out of consideration for their client, remediation companies are not in all cases allowed to publish the data of a remediation project. Therefore this list is not exhaustive, the cases have more an exemplary character.

4.1 General information

The site characteristics considers location of the contaminated site, the company which has implemented the technology and the year of remediation. Nearly all locations were situated in urban areas. Additionally in the case of Karlsruhe Durlach (Denzel et al. 2011) and case Landshut (Held 2012) the the challenge was to remediate below historical buildings which were also protected as cultural monuments.

4.2 Hydrogeological characteristics

The hydrogeological characteristics of the contaminated site for each case are included as well. Hydraulic conductivities are given (estimated) for most of the cases, as it plays a crucial role for the remediation process. In case Skuldelev (Lit) a barrier had to be built up in order to prevent huge amount of water comming into the remediation area. Furthermore in the case of Putzerei Alaska (Lit) water level had to be decreased as well.

4.3 Contaminants

The contaminats which are remediated in the examples are mainly VOCs like chlorinated solvents and BTEX, in some cases also PAHs. The initial concentrations of contaminants are given, as well as the concentrations after remediation and the remediation target values for soil, groundwater an soil air. Due to the law, in denmark only target values for soil are existing. A remediation succes is proven by taking core samples of soil. In United Kingdom target values are determined according to risk based target concentartions, so called generic assessment criteria (GAC).

4.4 Technical data

Some key figures are given like treatment area, depth and volume of treatment zone, as well as the number of heaters /injections wells or electrodes. The average heating temparature and the heating period make this overview complete.

4.5 Remediation results

Remediation results are presented by figures about removed amount of contaminants, the total energy consumption and the specific energy consumption in kwh/kg removed contaminants. The column for costs pro tonns of removed contaminants remains empty in most cases. It seems to be a top secret. A figure for the percentage of remediation efficency makes this overview complete.This figure is in every case above 90%, in several cases an efficiency of more than 99 % is given for soil.

Table 3: Overview of some completed thermal in situ remediation projects in Europe

3.1 general information	treatment method	**Thermal conductive heating**	**Thermal conductive heating**	**Thermal conductive heating**	**Thermal conductive heating**	**Thermal conductive heating**	**Steam air injection**	**Steam air injection**	**Radio frequency heating**	**Steam air injection**	**Steam air injection +thermal conductive heating**	**Radio frequency heating**
	location	**Odense, Denmark**	**Skuldelev, Denmark**	**Reerslev, Denmark**	**"Putzerei Alaska" Zwölfaxing, Austria**	**"Lederfabrik Berninger", Idstein, Germany**	**Biswurm, Villingen-Schwenningen Germany**	**Zeitz, Germany**	**Manston, Kent, United Kingdom**	**Karlsruhe Durlach, Germany**	**City of Landshut, Germany**	**Zeitz, Sachsen, Germany**
	pilot test or full scale	full scale	full scale	full scale	full scale	pilot test	pilot test (full scale now in operation)	pilot test	full scale	full scale	full scale	full scale
	company, year	Krüger A/S, 2008	Krüger A/S, 2008	Krüger A/S, 2009	reconsite, 2010	reconsite, 2010	VEGAS + City of Villingen Schwenningen, 2009	VEGAS, 2008	Ecologia, 2010	Züblin Umwelttechnik GmbH, 2010	reconsite, Bauer Umwelt GmbH, 2008	UFZ, 2008
	site characteristics	dry cleaning facility in operation	residental area	residental area, graveyard	former dry cleaning facility	former leather facility	former incineration plant for liquid organic waste (CHC, BTEX)	former hydrogenation plant, benzol factory	decommissioned petrol station	former dry cleaning company, remediation under historical building, built in 1547	former dry cleaning compar	former hydrogenation plant
3.2 hydrogeology	hydrogeology	clay, sand, saturated + unsaturated	clay, sand, saturated	clay, dry sand, unsaturated	silt, sand, clay, unsaturated	medium clay, unsaturated	fractured sandstone, saturated, unsaturated	gravel, coarce clay, unsaturated, sand, saturated	sandy clayey flint, brick gravel, porosity 39%, unsaturated	fracture zone, coarse clay, fine and medium sand, gravel, saturated and unsaturated	gravel, coarce clay, sand, unsaturated, saturated	
	estimated hydraulic conductivity [m/s]	clay: 1,00E-9 sand: 5,00E-5	clay: 1,00E-9 sand: 5,00E-9	clay: 1,00E-9 sand: 5,00E-9	not measured	not measured	5,50E-05	sand, clay: 0,50E-4 gravel: 5,00E-4	-	coarse clay: 1,00E-5 sand: 3,00E-4 gravel: 5,00E-3	-	
3.3 contaminants	type	PCE, DNAPL	PCE	PCE	mostly PCE	mostly TCE	CHC	BTEX (Benzol)	BTEX, total petroleum hydrocarbon (TPH)	CHC, PCE	CHC (mostly PCE, TCE), BTEX, TPH	BTEX
	concentration before remediation	soil max: 13.000 mg/kg	soil max: 2500 mg/kg	soil max: 7000 mg/kg	soil-air max: 2500 mg/m^3 GW max: 1500 µg/l	soil max: 160 mg/kg	soil-air max: 4 g/m^3 GW max: 40 mg/l	soil-air: 60 g/m^3 soil: 3,3 g/kg GW: 816 mg/l	TPH max: 23.500 mg/kg Toluene max: 20.400 mg/kg Xylenes max: 38.900 mg/kg	soil-air: 1.700 mg/m^3 soil: 3.820 mg/kg GW: 38.850 µg/l	soil-air: 7,9 g/m^3 soil: 1,0 g/kg strata GW: 24 mg/l	soil-air max: 90 g/m^3 soil max: 250 mg/kg
	remediation target	soil: 5 mg/kg	soil: 5 mg/kg	soil: 1 mg/kg	soil-air: 10 mg/m^3	-	soil-air: 145 mg/m^3	soil-air: 3,4 g/m^3 soil: 0,16 mg/kg GW: 1 µg/l	TPH: - Toluene: 870 mg/kg Xylenes: 480 mg/kg	soil-air: 10 mg/m^3 - GW: 10µg/l	-	
3.4 technical data	treatment area [m^2]	222	250	1.300	540	20	100	135	121	220	362	100
	depth of treatment zone [m]	10	7,5	10 - 12	3 - 7	5	20	11,5	7,5	8	6,5 (heater), 10 (injection well)	8
	treatment volume [m^3]	1.330	1.180	11.100	1600	100	2000	1.500	907	1.760	-	500
	number of heater / injection wells / electrodes	45	53	147	70	7	1	3	3	8	120 (heaters) + 3 (injection wells)	1?
	average temperature [°C]	100	100	100	69	107	50	75	49,1	92	110	54
	heating period [d]	105	73	169	290	43	175	252	117	294	90	100
3.5 remediation results	end concentration	mean: 0,51 mg/kg max: 4,4 mg/kg	mean: 0,02 mg/kg max: 0,77 mg/kg	mean: 0,012 mg/kg max: 0,057 mg/kg	soil-air: < 10 mg/m^3 GW: 50-200 µg/l	max: 17 mg/kg	soil-air max: 120 mg/m^3 GW max: 180 µg/l	soil-air: 0,175 g/m^3 soil: 0,1 mg/kg GW: 201 mg/l	- Toluene: 0,56 mg/kg Xylenes: 0,72 mg/kg	soil-air: 10 mg/m^3 - GW: 10µg/l	-	
	removed amound of contaminants [kg]	4.000	400	2.350	soil-air: 348 GW: 5	19,2	560	6.870	945	500	546	660
	total energy consumption [Kwh]	637.610	567.070	3.990.000	564.800	21.500	-	333.000	46.749	780.000	-	54.780
	specific energy consumption [Kwh/kg]	3.500	1.418	2.350	1.600	1.120	-	48	49	1.560	-	83
	costs pro tonns of removed contaminants [€/kg]	-	-	-	-	-	-	-	-	1.300	1.648	-
	remediation efficiency [%]	> 99	> 99	> 99	> 99	90	95	for soil and soil-air: 99	>95	99	-	

5 Conclusions

There are not many cases which are really well documented to make the efficiency and cost effectiveness of ISTR proof. Nevertheless ISTR may solve remediation problems which can not be solved in an adequate and quick manner with any other technique. Especially the short timeframe of the remediation and the possibility to remediate under existing buildings can be crucial for the use of ISTR. This can support the redevelopement off of urban areas. If ISTR is a cost-effective technique, can hardly be proven. Although cost estimations are made when selecting a remediation technique, the real costs are often higher in the end of the implementation. For ISTR high costs for drilling and energy are depending on the size of the site and the (hydro-)geology. Costs for planning and monitoring are high, regardless of the size of the sites. The adoption of the technique to the site specific conditions can be expensive and time consuming, in particular in urban environments. As ISTR generates high costs for energy consumption in a short timeframe, a thorough planning and supervision is necessary. In urban environments the costs for the supervision of neighboured buildings have to be taken into account.

Open questions:

- Applicability in low permeable subsoil and in the transition zone unsatured - saturated
- Which remediation targets can be reached? Crucial is the value for groundwater, but in most cases the result is given for soil.
- Is there a benefit with regard to time, costs and effort?
- The soil shrinkage manner caused by thermal heating is partly an open research question.
- Design data as guideline values for the planning of as orientation for future TCH or ERH projects (like the software tool for design of an steam air injection).

Further information and results of the pilot application in Stuttgart will be published on http://www.citychlor.eu/projects/pilot-project-5-thermal-treatment.htm and http://www.stuttgart.de/citychlor

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Summary: In situ thermal remediation (ISTR) is a technique for source remediation of organic compounds. It refers to the application of heat to the subsurface by various methods. Indepentent of the heating method the focus of ISTR is to mitigate source zone contam

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