ConSoil 2008 - Paper

Title of abstract	**IN-SITU THERMAL TREATMENT IN URBAN POLLUTED AREAS: APPLICATION OF THERMOPILE©**		
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Most appropriate theme (see Call: theme A-G)	E	**ORAL presentation** (type O) **or POSTER** (type P)	O
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Topics:
Thermal desorption, in-situ treatment, Thermopile©, urban polluted areas, thermal conduction, organic pollution, hydrocarbons, sustainable development.

IN-SITU THERMAL TREATMENT IN URBAN POLLUTED AREAS: APPLICATION OF THERMOPILE©

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Introduction

Urban areas have many contaminated sites where excavation is merely impossible, due to stability reasons, environmental impact or access. Most of the time, these sites are not properly remediated and contamination is managed in order to avoid its further spread, but the source remains in place.

Traditional in-situ technologies [1-4] are not suitable for treating heterogeneous soils and are therefore capable of reducing but not completely eliminating the pollution. This is especially the case for all venting/bio-venting and derived technologies as well as steam injection or electrical remediation, where preferential paths in the soil are the main limiting factor to the overall efficiency of the technology.

Compared to other soil properties, thermal conduction varies little according to soil type (clay, sand, lime, gravel, etc.) and is therefore much less sensitive as a means to reach contaminants than any other vector [5-7].

Thermopile© in-situ

Thermopile© is a technology based on thermal conduction that can effectively reach organic contaminants in-situ, independently of large soil heterogeneity. As with all thermal desorption technologies, Thermopile© reaches very low levels of organic contaminants (background levels), thereby releasing the site owner of any future liability, including the monitoring, reporting, follow-up or potential future clean-up of residual saturation.

The technology consists of installing stainless steel pipes in the soil, in which hot gases are circulated. The pipes are doubled (with an inner tube where hot gases enter and an annular zone – between both tubes – where the gases exit the pipe). The outer pipes are perforated and, as such, create a negative pressure in the whole zone to be treated. Thanks to the negative pressure and the conduction of heat in the soil, all organic contaminants are volatilized and migrate into the pipes (thanks to the perforations and the venturi effect of the high velocity circulating gases).

At the surface, the cold contaminated gases (approx. 400°C) are then brought into a thermal oxidizer where they are oxidized. The combustion gases (approx. 850-900°C) are recirculated and deliver their heat to the pipes, which themselves heat up the soil by conduction. The whole circuit is a quasi-closed loop.

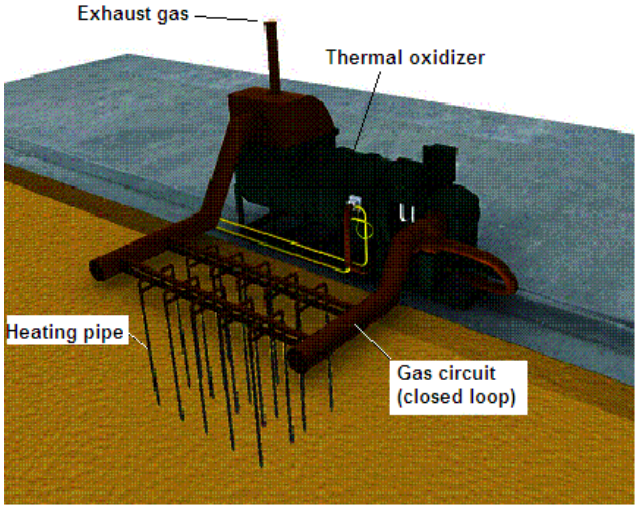


Fig 1. Thermopile© in-situ system

The technology has been applied in-situ at different sites where organic contaminants (such as fuel oil, diesel, PAH, coal tars, etc.) were present and demonstrated clean-up levels down to standard levels (< 10 mg/kg_dm for Total Petroleum Hydrocarbons for example), starting from very high concentrations (above 30,000 mg/kg_dm), in a few weeks.

The system is also particularly fuel efficient, by consuming much less energy (5 to 10 times) per ton treated than traditional thermal desorption. This fuel efficiency is mainly due to two factors:

1. Closed loop circuit – This allows the whole hot gas flow to be reused as much as possible and avoids high temperature flow gas release, which dramatically reduces energy efficiency. In this case, all gases are recirculated and only a very small purge gas flow, of which 70% of the energy is recuperated, is released into the atmosphere.

2. The pollutants in the soil serve as fuel – By desorbing all organic contaminants, Thermopile© uses them in the gas flow as a source of energy. All desorbed gases are sent to the oxidizing chamber, where they are burned to produce high temperature gases. These hot gases are then sent into the system in order to continue to heat up the soil.

In addition to the in-situ and fuel efficiency benefits, Thermopile© in-situ represents a leap forward in the environmental impact of thermal technologies. It reduces CO_2 emissions by a factor of 5 to 10, as well as total gas emissions (SO_2, NO_x, etc.). No dust emission, thanks to the specificity of the process where manipulation of soil is no longer carried out. Also local disturbances are much lower than with the traditional technology, as no moving parts are present in the system to handle the soil (screening, rotary kiln, etc.) and therefore noise and odours are almost inexistent.

Moreover, the in-situ application is fast. Treatment times are expressed in weeks (including mobilisation and demobilisation).

Case study: treatment of the Rue Bélliard site

Introduction

This article presents the results obtained through the use of in-situ Thermopile© on a polluted site in Brussels, near the European Institutions. The building has seven floors and the pollution was situated in the car park, located in the basement of the building. The ceiling was not higher than 3m, which made it very difficult to work with machinery.

History of the pollution

The owner of this centrally located office building wanted to sell his property. However, because of a previous mishandling of the tank fill there was an overflow of diesel and consequent soil pollution, the transaction could not take place. The buyer did not want to take over any risks associated with the pollution. In order for the transaction to take place, it was critical to definitively eliminate all pollution and so erase the site from the contaminated land register. Deep Green has been chosen to treat the site in-situ (no excavations) since it was the only technology offering a guaranteed result (i.e. clean soil) within a guaranteed timeframe (a couple of weeks).

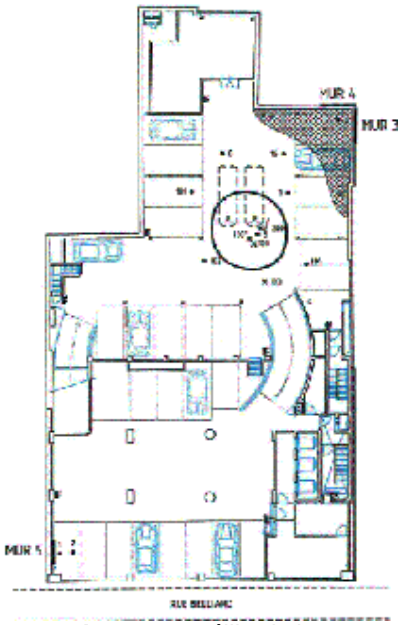


Fig 2. Rue Bélliard site

Fig 2bis. Rue Bélliard site

The site is an office building including two underground levels:
· Level -1: parking
· Level -2: technical buildings
Two underground storage tanks of fuel (2 X 20 m³) were located under the level -1.
January 25, 2006, following a handling mistake, an overflow of a tank was observed and thousands of litres of fuel were spread on the site:
- By the ventilation points on the parking on level 0; a part of fuel oil then infiltrated via the walls on the parking level -1 (hydrocarbon traces are visible on one of the walls of the parking);
- By the filling points located at the entry of the parking near street;
- At the level of the tank; fuel infiltrated into the technical room (level -2), hydrocarbon traces were visible on one of the walls of this room.

Description of the pollution and clean-up levels
Environmental consultants (Tauw) carried out a study to determine the vertical and horizontal impact of the pollution on the level-1.
The results showed that the main pollutants were hydrocarbons with linear links with a

maximum concentration of 63,000 mg/kg_dm. The pollution has been delimitated vertically at 16m (under level –1). The impacted surface was estimated at 35m² and so, a volume of 560m³ of polluted soil. The clean-up levels were set at 800 mg/kg_dm of TPH (Brussels Region standards).

The analysis of the groundwater showed that it was not polluted. So, the treatment had to be carried out very quickly. Indeed, the fuel contamination observed in the soil could be propagated in-depth towards the underground water. A risk of dissemination of the contamination in the groundwater could not be excluded.

Water sample		
Depth	16m	Standard level
TPH Concentration (µg/l)	120	500

Table 1. TPH concentration in underground water and standard level

Materials and methods

The Thermopile© system is made up of 19 heating pipes installed on an area of 35m² up to 16m deep. The heating pipes are placed in a triangle grid pattern (equilateral triangle) with a space of 1.5m between each other (figure 3). All pipes are connected to a horizontal gas network (figure 3). The gas, after going through the heating pipes, goes to the thermal oxidizer to be heated at 850°C. The gas circulation loop is done thanks to a fan of 5000m³/h (at 20°C). The thermal oxidizer, which was installed outside (figure 4), on the ground floor, is equipped with a fuel burner. A very small purge gas flow is released into the atmosphere and allows the pressure to be controlled in the system.

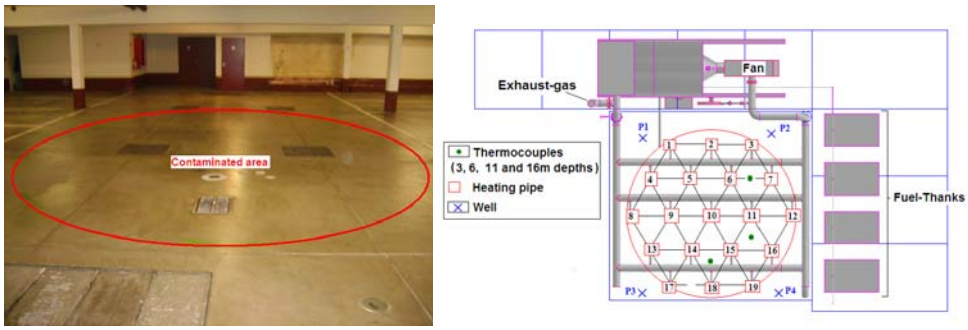


Fig 3. Contaminated area and Thermopile© installation

Fig 3bis. Pipe network on the polluted area

Fig4. Thermal oxidizer installed outside, on the ground floor, just above the polluted area

Heating pipe

The heating pipe is made up of two stainless steel concentric tubes. The 70mm-wide inner tube provides the pipe with hot gas. The 115mm-wide outer tube enables contact and thus heats the soil. To extract the vaporized products from soil, perforations are made on the entire surface of the outer tube. Since the site is located in the basement of the building whose ceiling is rather low, the pipes are installed in 3m pieces.

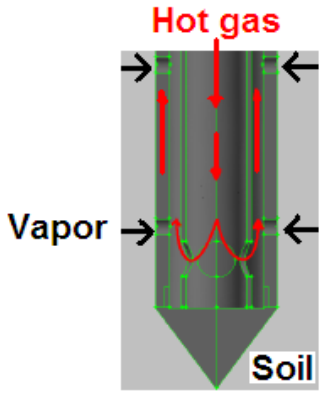
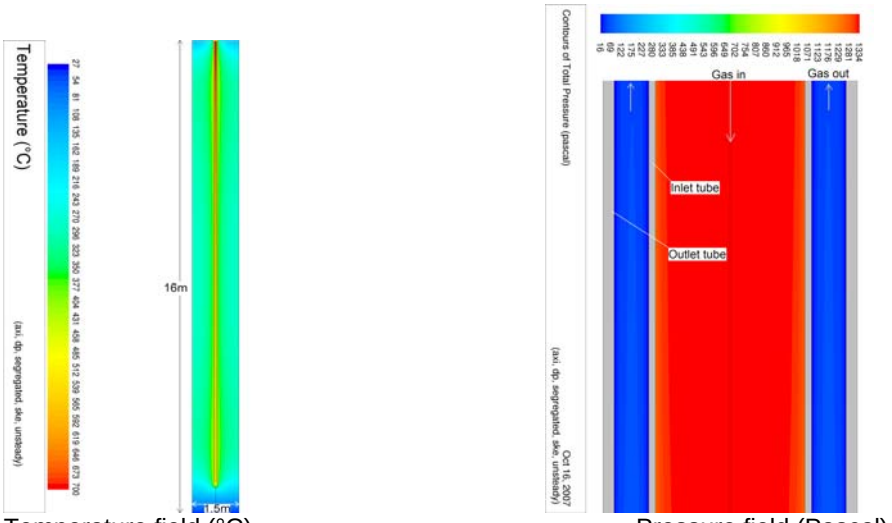


Fig 5. Heating pipe

In order to study the gas/soil heat exchange, and to determine the optimal heating power, some simulations of gas flow and heat exchange in non-stationary mode and in 2D axisymmetry, were carried out on a pipe of 16m surrounded by the soil (0.75m). Fluent© software is used.

Figure 6 gives the temperature and pressure fields after 25 days. The inlet gas speed in the inner tube was >15 m/s with a temperature in excess of 700°C.



Temperature field (°C) Pressure field (Pascal)

Fig 6. Temperature and pressure fields.

Groundwater control

In order to reduce energy consumption, 4 wells were placed with a depth of 20m around the treatment area (P1-P4; cf. figure 7). These wells allowed us to pump groundwater from the treatment zone. The pumping began 3 weeks prior to the treatment. The total flow pumped was 24m³/day. The pumping continued throughout the duration of the treatment.

Heat insulation and escaped gas treatment

To reduce heat loss, all system and soil surfaces were insulated. A 15cm layer of cement was laid on the soil. This layer prevented gas emissions in the atmosphere. In addition, the total system was protected with a watertight covering, which was capable of resisting high temperatures (550°C). The gases collected were sucked and passed through granulated activated carbon before release into the atmosphere.

Temperature measurement

12 type K thermocouples were located in the soil at different depths (Figure 7). The depths respectively were 3, 6, 11 and 16m. In addition, 10 thermocouples were placed on the gas circuit at the entry/exit of the pipes, on the feed gas line, in the thermal oxidizer and before the fan. The data logger used was the Microlink 751. The temperatures were recorded every 5 minutes.

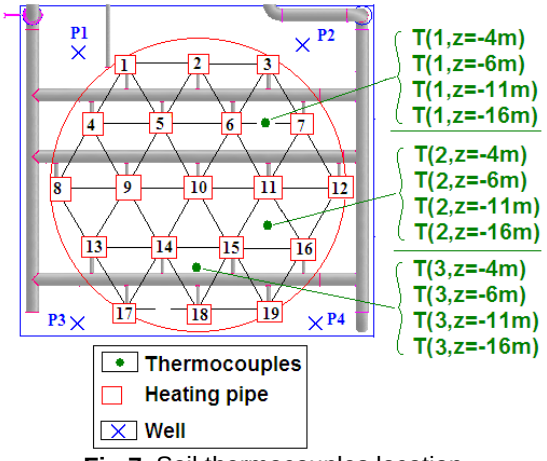


Fig 7. Soil thermocouples location

Gas analysis

The gases were analysed using an MRU Variousplus. Every hour, samples of gas from the

fan line, the thermal oxidizer and stack (purging gas) were taken. The analysed gases are NOx, CO, CO_2, O_2 , SO_2 and HCT.

Thermal oxidizer control

The most important parameter of the treatment is the combustion gas temperature. The parameter value chosen should allow us to have a greater yield of combustion and a higher inlet pipe gas temperature. The automatic setting of the burner air and fuel flows allowed us to guarantee a constant temperature at the exit of the thermal oxidizer.

Process control system

Given the long treatment time, the complete installation was equipped with an automatic control system. This system supervises gas temperature and pressure, the gas emitted and the air-site quality (confined space). If the limited values are exceeded, the installation is stopped following an automatic sending of an alert message by SMS.

Treatment time

Based on the mathematic model developed, the treatment time was estimated at 25 days. The heating began on December 3, 2007 and continued until December 28, 2007. During this period the temperature of the soil rose slowly until the final temperature of the treatment. The pumping of underground water continued throughout the duration of the treatment.

Results and interpretation

Soil temperature

Figure 8 gives the soil temperature at the centre of triangle formed by three heating pipes. These temperatures were measured by thermocouples, T(1,z=-4m), T(1,z=-6m), T(1,z=-11m) et T(1,z=-16m).

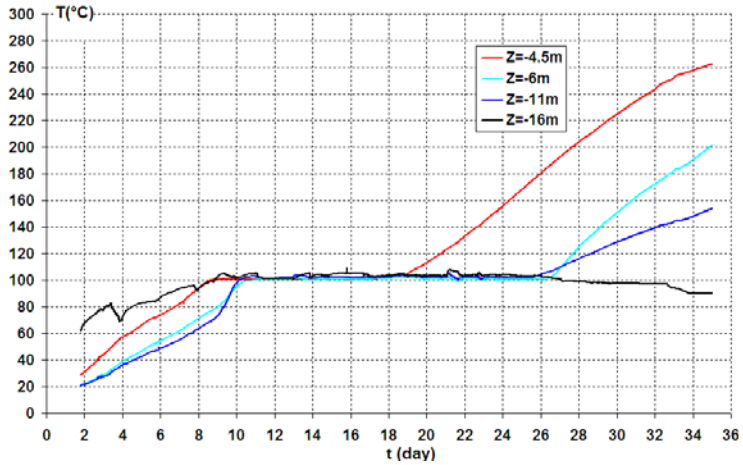


Figure 8. The soil temperature

In the first 11 meters, we can clearly distinguish three heating phases:

- First phase during which soil temperature rises to the boiling point of water (100°C).
- Second phase of water evaporation (stable at 100°C).
- Third phase during which soil temperature rises again to the final temperature of the treatment.

During the first phase, the soil and the liquids (water+contaminants) are heated to the boiling point of water. The time needed for this phase depends on the thermal properties of the soil and the quantity of water present. During the second phase, the soil temperature remains at the boiling point of water until the water-steam interface reaches the position of the thermocouple. The displacement speed of this interface varies according to the quantity of water present, the heating power and the speed of the steam sucked in. When all the water is evaporated, the temperature of the soil rises above 100°C. As the soil temperature increased, the organic components were volatilised and directed towards the openings on the outer tubes. Depending on the quantity of oxygen present in the soil, oxidative reactions and/or

pyrolyses were take place [8-9]. A large amount of the organic components were thus destroyed in-situ. The remaining quantity was destroyed in the gas circuit and in the thermal oxidizer, where the temperature exceeded 850°C.

Throughout the treatment and because of the presence of groundwater, the soil temperature for the last metres (2m) never exceeded 100°C (except around the heating tubes where T>400°C); the steam produced from the groundwater crossed a fine layer of sand (2m) and passed preferentially by the openings on the outer tubes. In this area, the main mechanisms of decontamination were evaporation, boiling and steam-distillation.

Gas control

Throughout the heating, gas analyses were carried out at different points of the circuit. These analyses made it possible to follow the evolution of the treatment. The gases analysed were O_2, CO_2, CO, C_3H_8, NO_x, and SO_2. The gas analyser used was the MRU-Varioplus. Table 2 gives an example of the results obtained on the 22nd day of the treatment. The analyses were carried out at the entry of the fan (Inlet-Fan) and at the exit of the thermal oxidizer (Outlet-Oxidizer).

	Position	T(°C)	O_2 [%]	CO_2 [%]	CO [ppm]	C_3H_8 [ppm]	NO_x [ppm]	SO_2 [ppm]
22 days	Inlet-Fan	489	6.95	9.9	650	189	47	14
	Outlet-Oxidizer	850	5.35	10.9	4	42	75	2

Table 2. Gas circuit composition

At the exit of the thermal oxidizer and throughout the treatment, oxygen concentration never exceeded 6%. This concentration was obtained thanks to a correct setting of the air/fuel burner ratio.

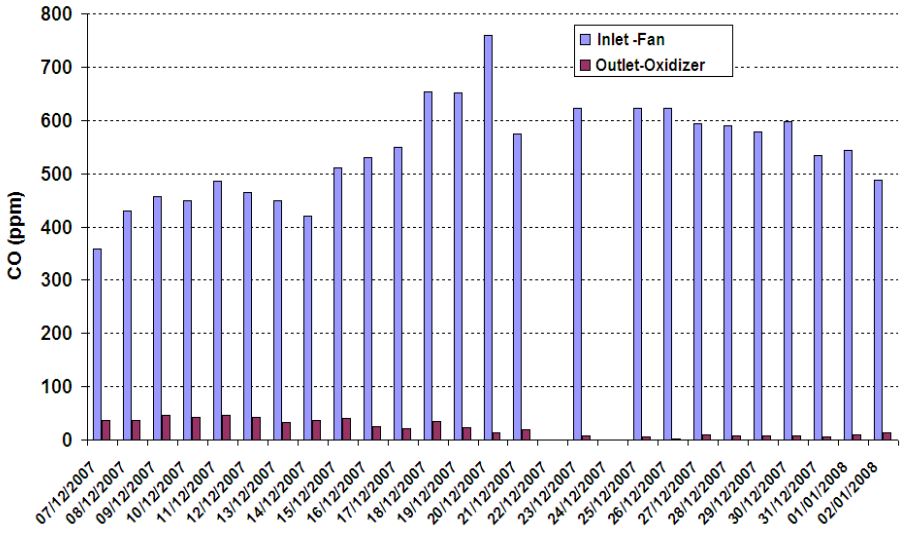


Fig 9. Evolution of carbon monoxide concentration.

To monitor the removal of hydrocarbons from soil, gas was analysed for carbon monoxide content. The carbon monoxide was essentially produced from a partial combustion of the hydrocarbons from the soil. As Figure 9 shows, the amount of CO at the inlet of the fan, increased progressively until 780 ppm then it decrease during the last days. This decrease corresponds to the reduction of the soil contaminant concentration. The propane was essentially produced from cracking reactions of hydrocarbons. These reactions take place in the soil and in the gas circuit where the temperature exceeded 400°C.

Soil analysis

Different soil samples were taken at different depths before and after treatment. The samples were analysed in an approved laboratory (Al-West). More precisely, analyses were carried out on the components shown in Table 3.

	PS	Pre-treatment					Post-treatment			
Depth		(2-3m)	(4-5m)	(7-7,8m)	(9–10m)	(11–12m)	(2,5-3m)	(5,5-6m)	(7-8,2m)	(13,5-14m)
Mono-aromatic Hydrocarbons (mg/kg_dm)										
Benzene	0,5	<0,50	<0,05	<0,05	<0,50	<0,50	<0,05	<0,05	<0,05	<0,05
Toluene	15	<0,50	<0,05	<0,05	<0,50	<0,50	<0,05	<0,05	<0,05	<0,05
Ethyl-benzene	5	<0,50	<0,05	<0,05	<0,50	<0,50	<0,05	<0,05	<0,05	<0,05
Ortho-xylene		<0,50	<0,05	<0,05	0,63	0,84	<0,05	<0,05	<0,05	<0,05
Meta- et Para-xylene		<0,50	<0,05	<0,05	0,60	0,79	<0,05	<0,05	<0,05	<0,05
Xylenes	15	<d	<d	<d	1,2	1,6	<d	<d	<d	<d
Poly-aromatic Hydrocarbons (mg/kg_dm)										
Naphtalene	5	48	4,7	5,1	3,8	3,9	<0,05	<0,10	0,099	<0,10
Benzo(a)pyrene	1,5	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Phenanthrene	65	NA	NA	NA	NA	NA	NA	NA	0,27	NA
Fluoranthene	30	NA	NA	NA	NA	NA	NA	NA	0,011	NA
Benzo(a)anthracene	10,5	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Chrysene	180	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Benzo(b)fluoranthene	7	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Benzo(k)fluoranthene	11,5	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Benzo(g,h,i)perylene	3920	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Indeno(1,2,3-c,d)pyrene	20	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Anthracene	70	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Fluorene	3950	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Dibenzo(a,h)anthracene	1,5	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Acenaphthylene	14	NA	NA	NA	NA	NA	NA	NA	<0,050	NA
Acenaphtylene	1	NA	NA	NA	NA	NA	NA	NA	<0.050	NA
Pyrene	395	NA	NA	NA	NA	NA	NA	NA	<0,010	NA
Total 6, Borneff									0,01	
Total 16, EPA									0,38	
Petroleum Hydrocarbons (mg/kg_dm)										
Total (C10-C40)	1000	**63000**	12650	13000	7630	9070	<20	<20	113	36
Details										
C10-C12		NA	1680	NA	640	900	<4	<4	<4	<4
C12-C16		NA	4860	NA	2850	3580	<4	<4	20	<4
C16-C20		NA	3985	NA	2590	3050	<2	<2	42	9
C20-C24		NA	1620	NA	1180	1210	<2	<2	39	14
C24-C28		NA	417	NA	290	280	<2	<2	8	7
C28-C32		NA	48	NA	45	41	<2	<2	<2	<2
C32-C36		NA	<20	NA	<20	<20	<2	<2	<2	<2
C36-C40		NA	<20	NA	<20	<20	<2	<2	<2	<2

PS : Pollution Standards; NA : Not Analysed; <d : lower than detection; dm: dry matter.

Table 3. Results of soil analysis (in mg/kg_dm) before and after treatment. Comparison with norms.

All results of soil analysis after treatment show a total concentration in TPH, which does not exceed 113 mg/kg_dm. This concentration is largely inferior to the standard level (800 mg/kg_dm). The results show also the elimination of BTEX and PAH.

Conclusion

The results achieved at the Bélliard site show the effectiveness of the Thermopile© in-situ technology in the treatment of organic contaminated soils. This technology – easy to set up and dismantle – allows, for example, the treatment of difficult-to-access areas; areas where the excavation of the soil presents a danger for the building stability for instance. The technology is also suitable for saturated soil. Nevertheless, a study of the quantity of water present and the reduction of this quantity (by pumping, reducing the groundwater level) is essential to reduce energy costs. The treatment at the Bélliard site took place as planned and the objectives were largely met: concentrations of TPH did not exceed 113 mg/kg_dm, compared to the initial mean value of about 12,000 mg/kg_dm. The deadline was met, within budget.

Acknowledegments

The authors are grateful to the Brussels Region work for their financial support.

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