European Union Network for the Implementation
and Enforcement of Environmental Law

Annex 1

Multi Phase Extraction – Case studies

IMPEL Project no. 2021/08 WG6

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2. Site background

2.1 History of the site

The Site is a petrochemical plant in Italy, built starting from the 1960s, was characterized by a differentiated production structure which has undergone considerable variations over time. The plant has a total extension of over 1100 ha.

During the first and second phase of development, production activities were started and subsequently, in 1965, those for the construction of the first Steam-Cracking plant (currently demolished), which allowed the construction of other plants for the subsequent use of Ethylene.

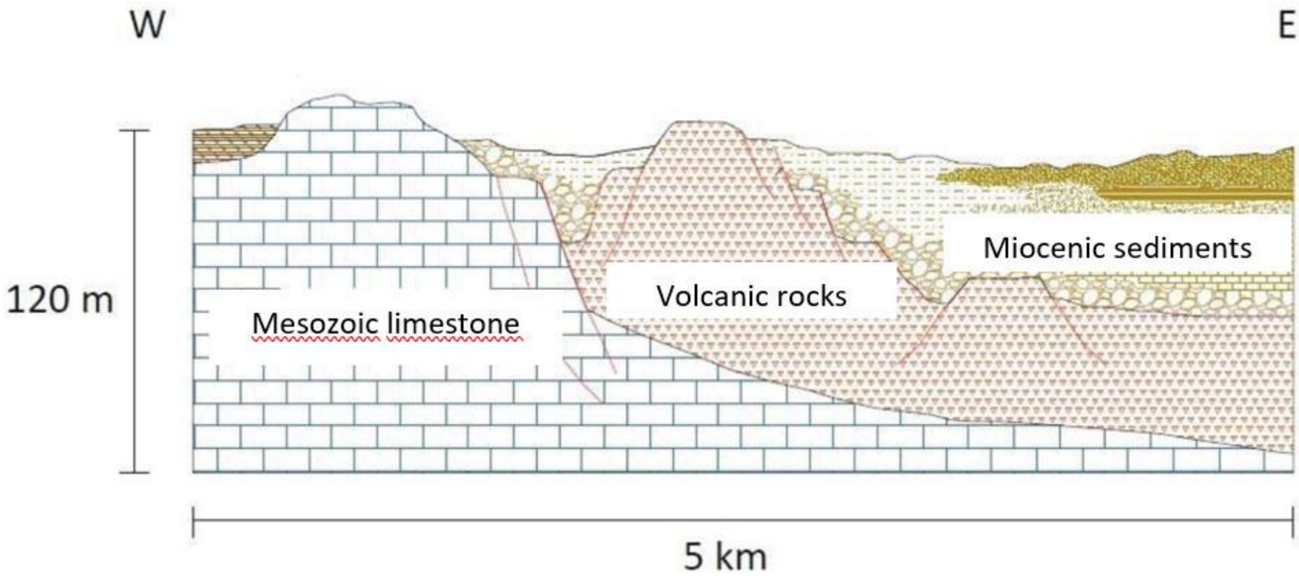
In 1967 was built the refinery. The refinery was then decommissioned in the 1980s.

At the end of the 1970s, the third phase of development of the plant began, which involved the construction of the chlorine and chlorine derivatives plants, the second steam cracking plant, the plants for the production of PVC, polystyrene and polyethylene, until 1976, the year of construction of the plant for the production of Acrylic Fibres.

From April 1982 the plant took a configuration almost similar to the current one.

Starting in the late 1990s, the productivity level dropped and the plant was slowly decommissioned.

2.2 Geological setting



Geology of the site consist in oligocenic volcanic/mesozoic limestone bedrock, underlies a thick miocenic sequence.
The depth to ground water changes as a function of the local stratigraphy. At site where MPE is installed, the depth to groundwater is approximately 10-15 meters below ground surface.

2.3 Contaminants of concern

The site is contaminated both in soil and in the aquifer.
MPE technology is used on site for groundwater remediation, currently in one of the plant areas, characterized by the presence of free phase product (LNAPL) and dissolved contamination.
The main exceedances of target limit (CSR) in groundwater, in correspondence of the areas where the MPE systems are installed, refer to:

- total hydrocarbons;
- aromatic hydrocarbons (benzene, toluene);
- organohalogen compounds (1,2-dichloroethane, 1,1,2-trichloroethane, vinyl chloride, trichlorethylene).

2.4 Regulatory framework

The main environmental law in Italy is the Legislative Decree no. 152/2006 (D.Lgs. 152/06) that in Part four, Title fifth sets specific rules for remediation of contaminated sites.
The reference legislation establishes some threshold limit values (CSC D.Lgs. 152/06) for the main existing contaminants both in soil and groundwater, if during the characterization there are one or more exceedance of these value, the site is defined "potentially contaminated", and a risk assessment can be elaborate to estimate the risks deriving from the potential sources of contamination detected on site (defined by the samples with exceedance). The legislature also fixes which are the values of acceptable risk to compare with the values derived from the site's risk assessment.
If the estimated risks are lower than acceptable values, the site is defined "not contaminated", and no remediation is needed. If the estimated risks are higher than acceptable values, the site is defined "contaminated", and remediation is needed. The legislation also allows to define, via risk assessment, new site-specific threshold limits (CSR defined by Italian law D.Lgs. 152/06), which becomes the remediation targets.
At the site specific threshold limits were available both in groundwater and soil.

3. Pilot-scale application in field

3.2 Feasibility study

The objective of conducting the MPE pilot test is to verify the applicability of the technology for site remediation and to define some process parameters. In particular, the pilot test will have the aim of:

- evaluate the removal capacity of the LNAPL product in the wells;
- measure the flow rates of extracted fluids;
- check the chemical characteristics of the extracted vapors;
- measure the induced depressions in the suction well;
- evaluate the effectiveness of MPE technology in the removal of fluids from wells with a depth of even more than 15 m;
- collect any other data useful for the design.

The system used for the pilot tests simulates the operation of the MPE plant designed for the site.

The extraction will take place through a well, which will be equipped with a sealed wellhead to which two pipes will be connected: one, at high depression, for multiphase suction (air / water / product), and the other, at low depression, for the aspiration of the air/VOC.

The wellhead will be equipped with a pressure gauge for measuring the depression in the well and a hole with suitable sealing for measuring the subsidence of water and product.

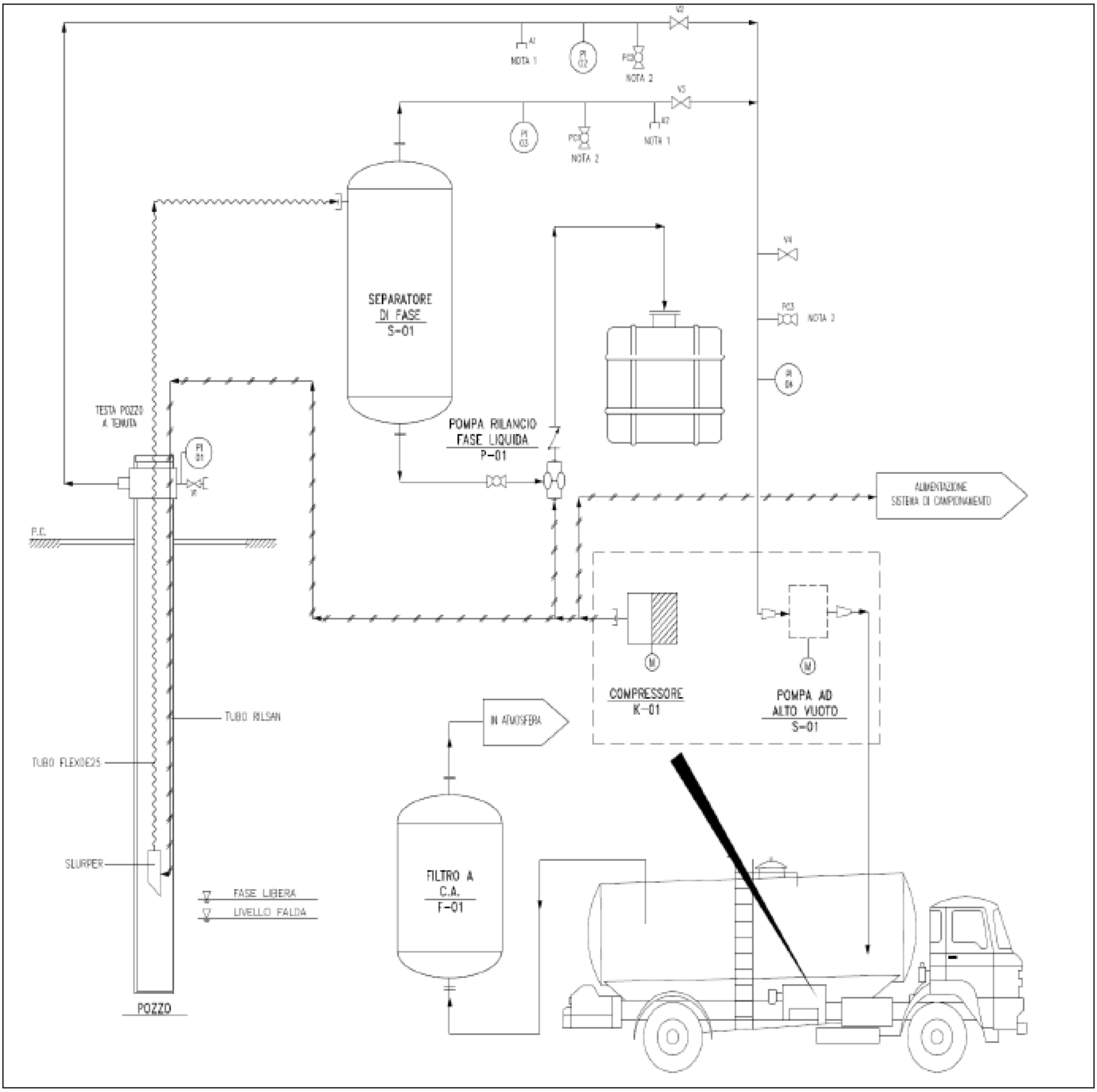
The suction will be generated with a high vacuum pump supplied with a self-purge device. This expedient will facilitate the logistics of the tests, avoiding the need to set up the connection to the system's electrical network and facilitate the management of the waste produced by the tests.

The flow extracted from the high-vacuum line will be passed through a phase separator where the air/fluid (water and product) separation of the high-vacuum flow will take place.

The aqueous phase and the product that will accumulate in the separator will be sent by means of a pneumatic diaphragm pump to a tank with a capacity of 1 m^3 for temporary storage before final disposal.

The compressed air for powering the pump will be generated by the generator supplied with the self purge.

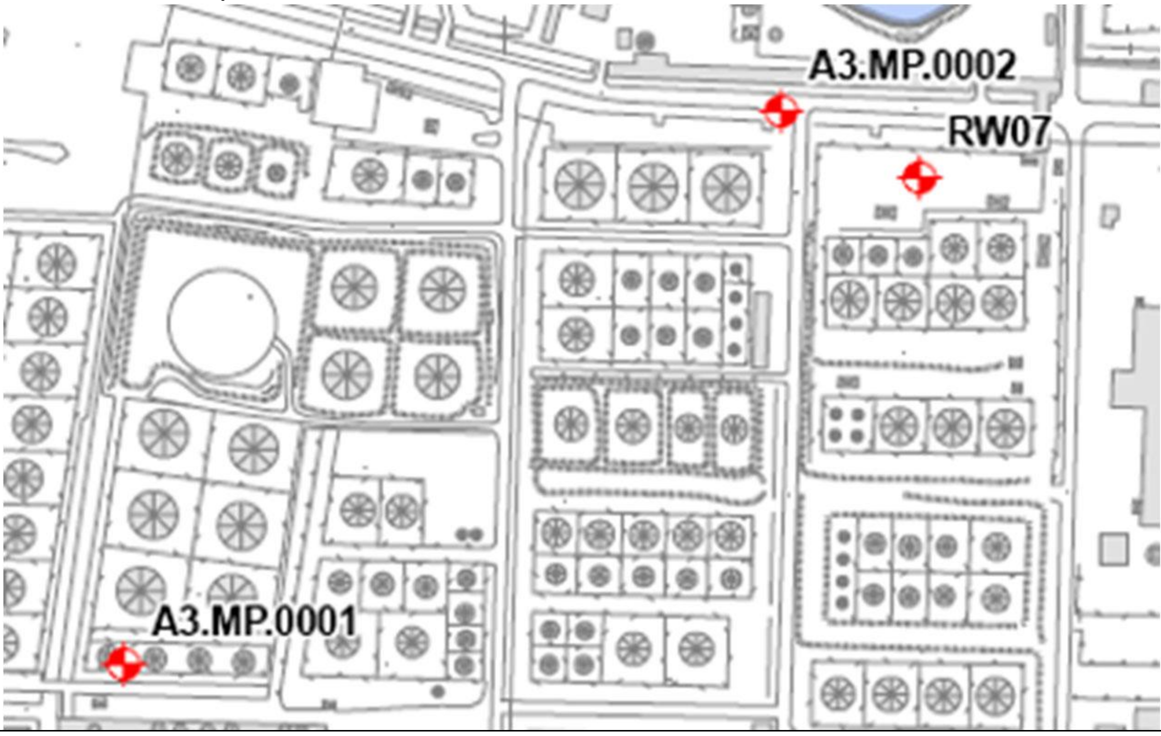
Below some schemes and picture of the pilot test system.


SEPARATORE DI FASE
S-01
POMPA RILANCIO FASE LIQUIDA
P-01
TESTA POZZO A TENUTA
P.C.
ALIMENTAZIONE SISTEMA DI CAMPIONAMENTO
COMPRESSORE
K-01
POMPA AD ALTO VUOTO
S-01
TUBO RILSAN
TUBO FLEXDE25
IN ATMOSFERA
SLURPER
FASE LIBERA
LIVELLO FALDA
FILTRO A C.A.
F-01
POZZO
NOTA 1
NOTA 2


S13AM
A01TD
S12AM
S32 MR
S02GA
MiniRAE Lite

3.3 Radius of influence

The pilot test did not foresee the drilling of new points to be equipped with extraction wells and / or monitoring piezometers.
Existing piezometers were used for the test and, not being present in the circumscribed surroundings of the points selected for the execution of the monitoring piezometers pilot test, it was not possible to define a radius of influence.



3.4 Off gas Treatment

The gases extracted during the test were sent to an activated carbon filter before being released into the atmosphere.

3.5 Water Treatment

The aqueous phase and the product that accumulated in the separator during the pilot test were sent by means of a pneumatic diaphragm pump to a tank with a capacity of 1 m^3 for temporary storage before final disposal.

3.6 Control parameters

During the pilot test the following parameters were monitored:

- water / product subsidence
- vacuum, temperature and flow rate of the extracted gases (on the high and low vacuum lines,
- upstream of the sampling pump)
- VOC
- CO_2, O_2 and CH_4 concentrations on high and low vacuum lines
- volume of water and extracted product
- wellhead depression

Vapors were also sampled on both the high and low vacuum lines using a sampling pump and activated carbon vials, before starting the tests and at the end (60 minutes after starting) of each MPE test for the determination of the contaminants of interest.

4. Full-scale application

4.1 Full design system

4 MPE modules were installed on the site, each consisting of 45 extraction wells 15 to 20 m deep.

The MPE system installed at the site was sized considering that:

- each MPE module has been designed so as to intervene on the areas characterized by the highest concentrations of hydrocarbon compounds in the dissolved phase, in the vapour phase and by the probable presence of LNAPL;
- the installation depth of the MPE wells is related in each installation area to the average depth of the groundwater level, the maximum oscillation of the groundwater level and the thickness of the capillary fringe;
- the radius of influence of the extraction wells was estimated to be around 5 meters.

The suction of low and high vacuum flows is achieved by generating a vacuum in the pipes by means of special suction modules, respectively equipped with blowers and high vacuum pumps.

The separation of the different phases (liquid and gaseous), which make up the flows extracted from the subsoil, starts through the passage in a special separation module, in which the condensate precipitates from the low depression flow and the air / aqueous phase separation. (water and product) of the high depression flow.

Each module making up the system consists of the following sections:

- 45 extraction wells: each well is equipped with 2 lines, one of which with high depression, for multiphase suction (steam / water / product) and one with low depression, for suction of the vapour phase only;
- 9 separation modules: each separation module manages 5 extraction wells and allows the precipitation of the condensate of the low-vacuum flow and the vapour / liquid (water and product) separation of the high-vacuum flow;
- 1 suction module (high and low depression lines): each suction module manages 9 separation modules and has the purpose of generating the air flow and the degree of vacuum required by the system;
- 1 treatment module: each module treats the vapour phase by means of 3 activated carbon filters and stores the liquid phase in a temporary storage system with subsequent re-launching for treatment;
- a module containing the compressed air production systems and the main management and

- Control unit of the treatment suction separation modules;
- Exhaust duct.
- The four suction modules deliver the liquid phase to a water / oil separator, where the LNAPL is separated and collected and the water phase is pumped to the groundwater treatment system.
- The hydrocarbon product leaving the oil separator is sent to the preliminary liquid deposit for subsequent disposal to an authorized external plant.

4.2 Different areas characteristics that affect the project

The 4 modules were installed in areas with similar geological and hydrogeological characteristics. The same inter distance has been maintained for all extraction points of each module.

4.3 Radius of influence

In the absence of specific site data, the radius of influence of the extraction wells was taken as a precaution, considering the geological and hydrogeological characteristics of the area, equal to about 5 meters, taken as a precaution, considering the geological and hydrogeological characteristics of the area, equal to about 5 meters.

4.4 Off gas Treatment

The gaseous flow leaving the MPE plant is treated by activated carbon filters connected in series.

4.5 Control parameters

The water extracted from the MPE system downstream of the oil separator is sent to the site groundwater treatment plant.
The current structure of the groundwater treatment plant to which the water extracted from the MPE systems (but not only) flows is composed of the following units:

- oil removal;
- chemical-physical treatment
- storage;
- sand filtration
- acidification;
- steam stripping
- activated carbon filtration;
- neutralization;
- sludge treatment (thickener and filter press);
- Vapour treatment (condensation and filtration on activated carbon).

4.6 Control parameters

MPE interventions are subject of a plant and environmental monitoring program aimed at keeping system functionality and evolutionary trends in terms of mass of contaminant removed under constant control, so as to determine the best performance obtainable in site-specific conditions.
As regards the environmental status, the plan provides for the following monitoring:

- phreatometric and the possible presence and thickness of free product (LNAPL), in correspondence with a network of 16 piezometers;
- the quantity of product recovered from each MPE module;
- hydrochemical of groundwater, at 24 points of the network of selected piezometers;
- Soil gases through field measurements, at 80 selected extraction wells;
- Soil gases by sampling and chemical analysis in the laboratory at 80 selected extraction wells.

From the plant engineering point of view, the following are detected:

- water / product subsidence in MPE wells
- vacuum, temperature and flow rate of the extracted gases (on the high and low

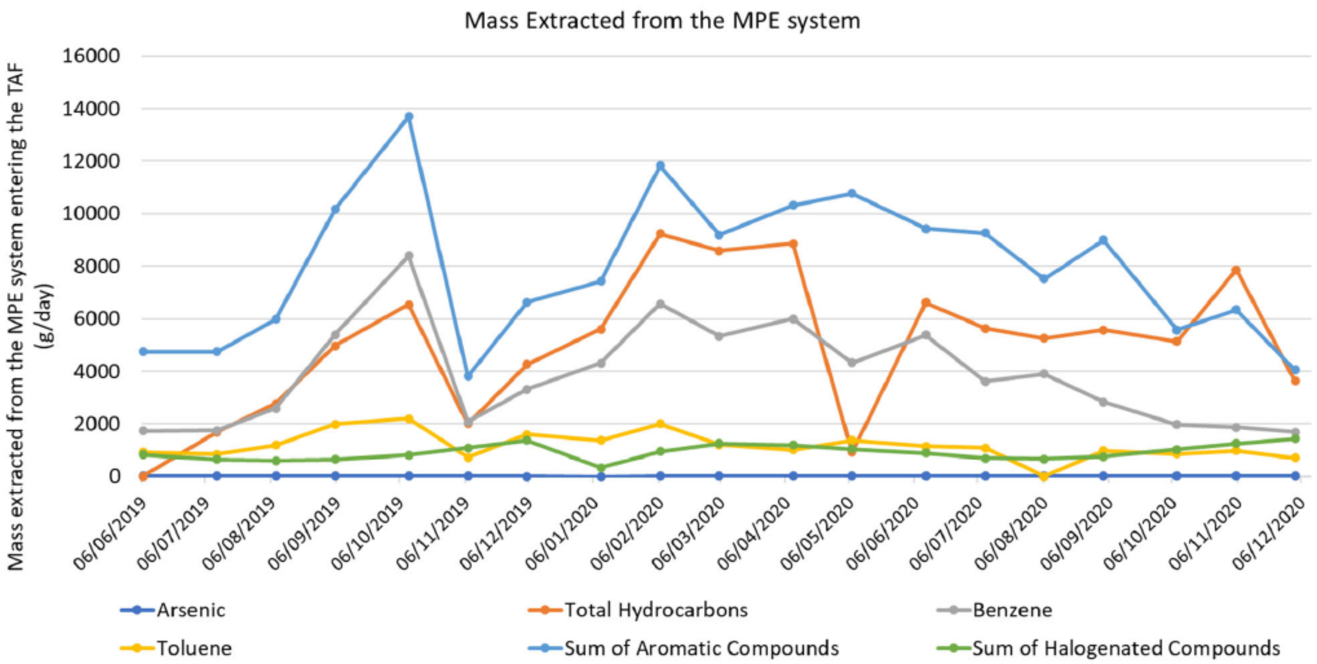
vacuum lines, upstream of the sampling pump)

- VOC at the wellhead
- concentrations of CO_2, O_2 and CH_4, VOC on high and low depression lines
- volume of water and cumulative extracted product
- wellhead depression.

5. Results

5.1 Removal rate

For the determination of the extracted mass, five index parameters are analyzed on the water drawn from the MPE system, such as arsenic, total hydrocarbons (expressed as n-hexane), benzene, toluene and the sum of the total and aromatic organohalogen compounds, using the results of the chemical analyzes performed monthly upon entry to the groundwater treatment system. The graph shows the trend of the mass of contaminant extracted, expressed in grams / day, in about a year and a half of operation of the MPE systems.



6. Post treatment and/or Long Term Monitoring

6.1 Post treatment and/or Long Term Monitoring
The MPE plant (4 modules) after carrying out the baseline monitoring, entered the start-up phase for about 6 months and starting from June 2019 was fully operational and is still in operation.

7. Additional information

7.1 Lesson learnt
In order to ensure optimal functioning of the systems, the following aspects are important: • Carry out periodic routine and extraordinary maintenance • Check the correct positioning of the slurper according to the depth to groundwater level and the depth to water / product interface • Continuous operation of the system and constant adjustment of the process parameters.

Glossary of Terms

Term (alphabetical order)	**Definition**
CSC	Threshold limit values according to 152/06 Decree
CSR	Site-specific threshold limits according to 152/06 Decree
LNAPL	Light not acqueous phase liquid

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2. Site background

2.1 History of the site

The site is a gas station in a city of central Italy, where at least starting from 1968, the marketing of petroleum products for motor vehicles, refuelling of motor vehicles, sale of lubricants and oil change of cars have been carried out. A contamination of TPH affecting soil and TPH, Benzene, MTBE, ETBE, Lead affecting groundwater (with also LNAPL) was found there in 2010. So First Remediation Phase took place in 2012 and consisted of removing the contaminated soil simultaneously with the renovation of the mechanical system of the gas station. As Second Remediation Phase a groundwater and unsaturated soil remediation plant was installed using MPE and P&T technology in 2014.

2.2 Geological setting

The site is located in a hilly city, with the presence of some waterways characterized by a distinctly torrential regime.
The investigation carried out here has shown the presence of a succession of an alluvial nature at the site in which two units are identified: a superficial silty-clayey up to an average depth of about 5 m b.g.s., and a predominantly sandy underlying up to the maximum depth investigated (8 m b.g.s.).
The investigation carried out here showed the presence of an aquitard contained in the superficial part of the alluvial unit consisting of low permeability deposits.
The average piezometric level is about 2.0-2.5 meters deep from the ground level.
The presence of a confined aquifer with good permeability was found in the underlying sandy layer, whose piezometric level is about 3.0-3.5 m from the ground level.

2.3 Contaminants of concern

As anticipated the historical contamination affected both soil and groundwater, with TPH as CoCs in the first and TPH, Benzene, MTBE, ETBE and Lead as CoCs in the latter.
The residual contamination downstream of the remediation work carried out on the site in 2012 was present in the adsorbed phase in superficial and deep unsaturated soil and in the dissolved phase in the superficial aquitard and in the deep aquifer.

2.4 Regulatory framework

In Italy the environmental regulatory system is regulated by Legislative Decree No. 152/06 and for fuel stations by the Ministerial Decree No. 31/15. For the implementation of MPE and P&T technology (as well as for the implementation of any remediation plan) the approval by local authorities is needed.

3. Pilot-scale application in field

3.1 Extraction system

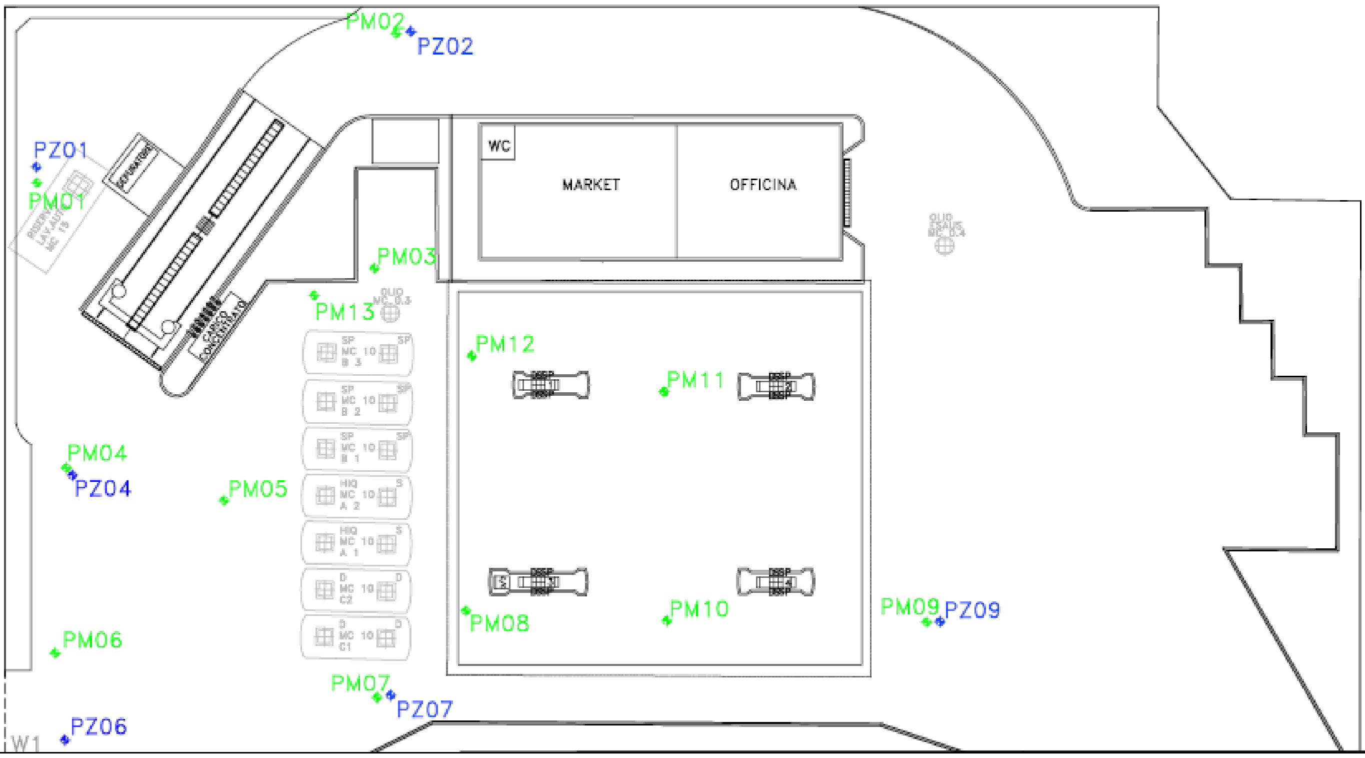
Single Pump configuration (extract air and liquid)

- Dual Pump configuration (submersible pump for groundwater recovery in conjunction with a separate vacuum applied at the sealed wellhead)
- Bioslurping (extraction at the interface air liquid)
- Other
  - High-Vacuum Dual Phase Extraction (HVDPE)
  - Low-Vacuum Dual Phase Extraction (LVDPE)
  - …….

For the pilot test, the PM03 and the monitoring piezometers arranged "helically" around the aforementioned piezometer were chosen as extraction piezometer, i.e. at about 120° and with increasing distances the PM13 (2.9 m), PM12 (5.8 m) and PM02 (10.4 m), as indicated in the figure below.

The test was performed by applying 3 different flow rate steps (30, 45 and 50 Nm^3/h) in PM03, while analyzing the relative subsoil response (in the monitoring piezometers); the drop-tube was applied near the bottom of the hole.

The drained waters were deposited on site and subsequently disposed of in accordance with current legislation, while the air was purified of any organic contamination contained in the flow by means of a granular activated carbon (hereinafeter GAC) filter.



3.2 Feasibility study

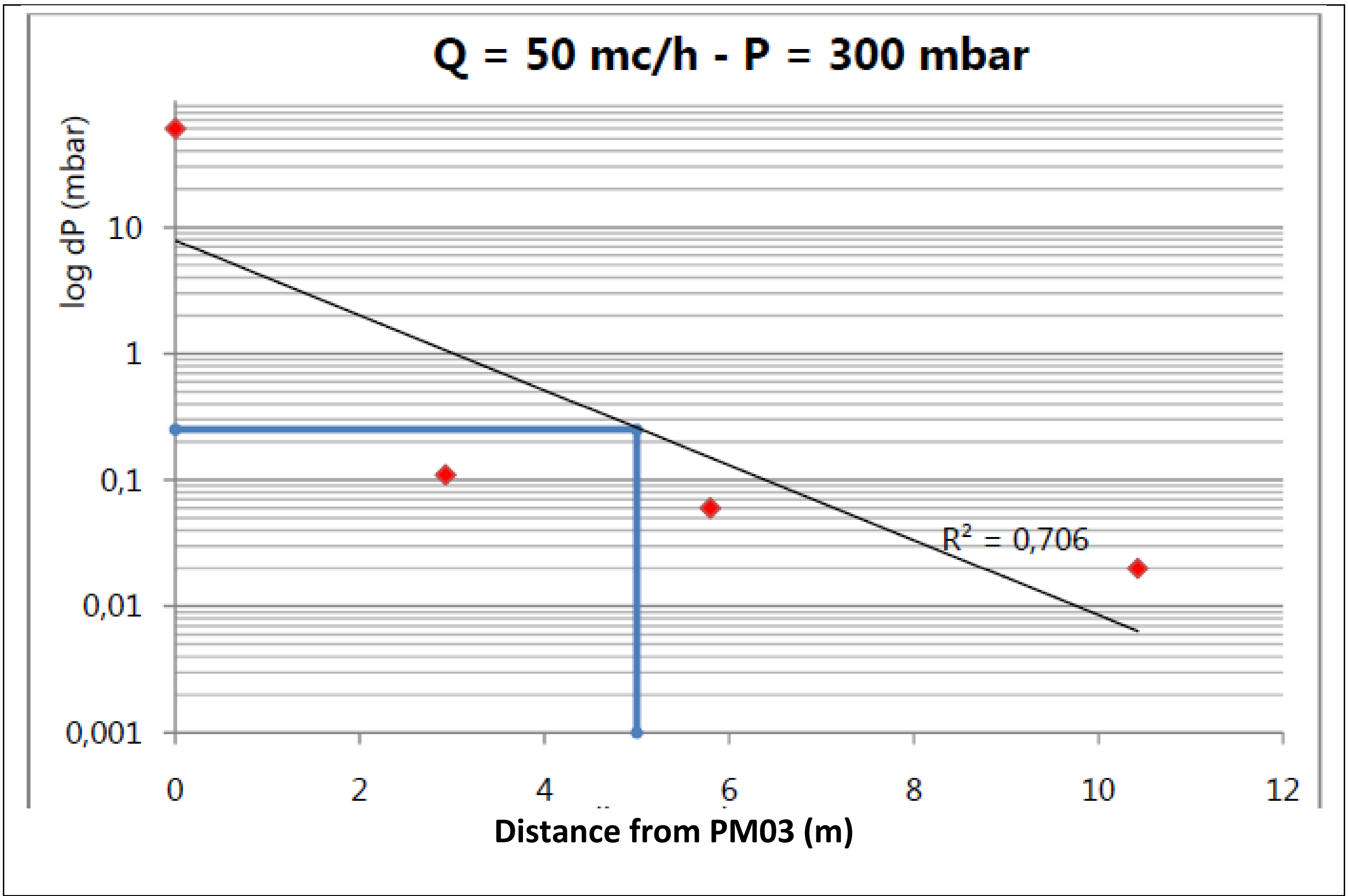
The pilot test was performed in order to:

- verify the applicability of the MPE system in the geological, hydrogeological and environmental context of the specific site;
- determine the radius of influence of the depression (hereinafter ROI), conventionally defined as the distance, from the extraction point, where a relative depression of 0.25 mbar is recorded;
- determine the minimum depression to be applied for the extraction of the liquid phase;
- define the achievable extraction rates;
- estimate the concentrations of the Volatile Organic Compounds (hereinafter VOC) extracted.

The MPE pilot test demonstrated good applicability to the specific geological, hydrogeological and environmental context in terms of subsoil response to the stress induced by the system.
Simultaneously with the MPE pilot test, the step flow test was implemented, in order to obtain the characteristic curve of the well under test, while with the long-term pumping test the trasmissivity, the storage coefficient of the portion of the aquifer around the PZ04 well, as well as the radius of influence of the extraction.

3.3 Radius of influence

As shown in the figure here below, the ROI of the extraction system positioned in the PM03 piezometer, with an air flow rate of 30 Nm^3/h and a pump vacuum of -500 mbar, is approximately 6.5 m, with an air flow rate of 45 Nm^3/h and a vacuum at the pump of -300 mbar, the ROI becomes about 4.5 m, and with an air flow rate of 50 Nm^3/h and a vacuum at the pump of -150 mbar, it becomes about 5 m.



3.4 Off gas Treatment

For the abatement of any pollutants present in the extracted air, downstream of the air/liquid separation system, a pair of activated carbon filters for air in iron with epoxy treatment was provided, with a plating height of 1300-1500 mm and diameter 800-1000 mm.

3.5 Water Treatment

For the abatement of any pollutants present in the discharged water, a pair of activated carbon filters for water in iron with epoxy treatment was provided downstream of the water/oil separation system, with a plating height of 1100 mm and diameter 800 mm.

3.6 Control parameters

During the test, the following data were recorded, for each flow step applied on PM03:

- Flow rate of extracted air (Qa) and extracted water (Qw);
- Depression upstream of the pump (PIN) and induced on the wellhead;
- Concentration of extracted VOCs (VOCIN) and out of the GAC filter (VOCOUT);
- Temperature (TOUT) on the discharge line downstream of the pump.

At the same time, depressions (dP) and groundwater levels (Lgw) were recorded in the monitoring piezometers PM02, PM12 and PM13.

4. Full-scale application

4.1 Full design system

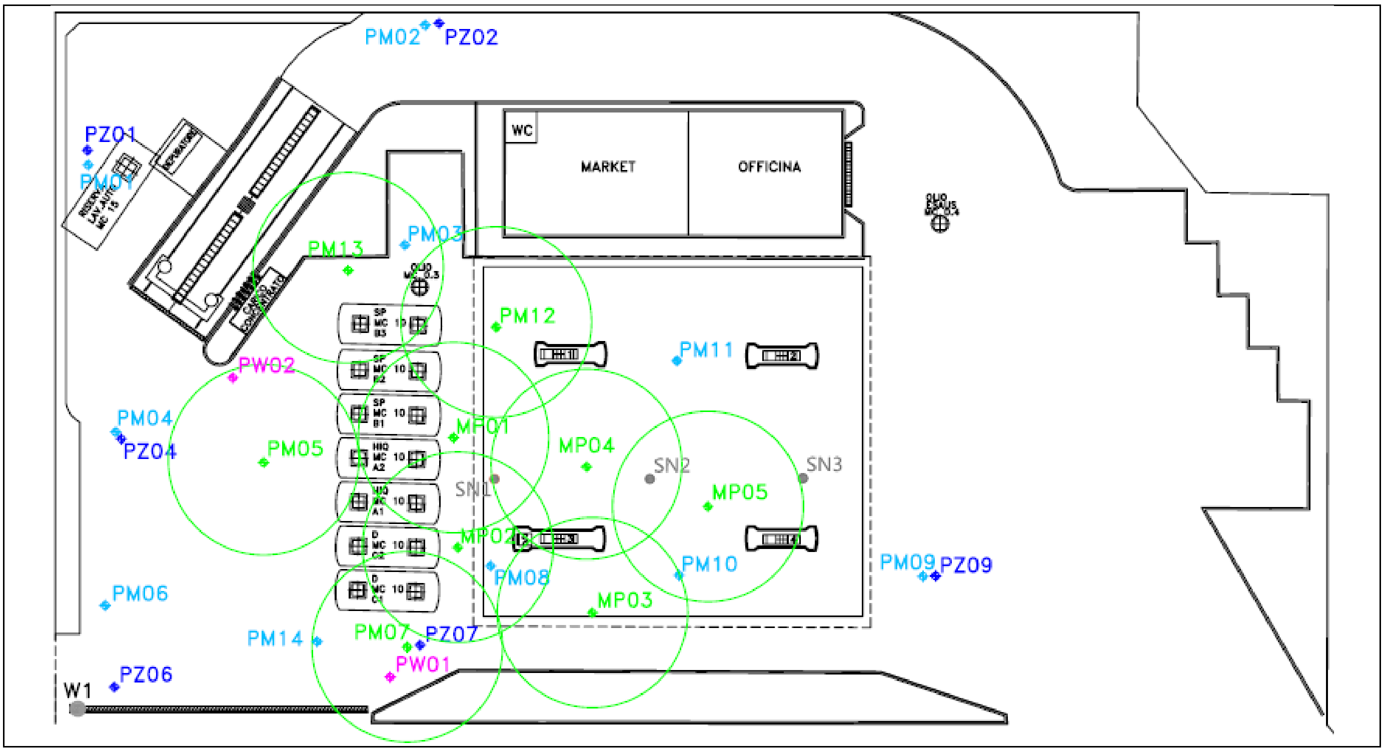
The MPE remediation system launched in 2014 consisted of n. 9 multi-phase extraction points (called PM05, PM07, PM12, PM13 and MP01÷MP05) in bio-slurping configuration (simultaneous aspiration of water, air and any product).
The MPE system provided that the emulsion extracted from the wells was conveyed inside a separator (S1) which separated the gaseous flow from the liquid one; the latter was collected, by gravity, inside an accumulation tank (T1).
The gaseous flow, once separated from the liquid phase, passed through the air handling unit (AT) consisting of a pair of filters in series, containing GAC.
At the exit of the AT unit, the air then passed through an anti-particulate filter before entering the vacuum pump and being discharged into the atmosphere.
The liquid flow accumulated in T1 was sent, by means of an electric pump (EP1), to an oil separator (S2) which guaranteed the separation of water and product.
Any product separated in S2, thanks to an overflow system, was collected by gravity inside a drum (T3).
The waters separated in S2 were collected by gravity inside a tank (T2); from here they were sent back to a treatment unit (WT), consisting of two filters in series containing GAC.
The water leaving the treatment was then discharged into the public sewer.

4.2 Different areas characteristics that affect the project

As anticipated within the site there are an aquitard contained in the superficial part of the alluvial unit consisting of low permeability deposits and a confined aquifer with good permeability in the underlying sandy layer.

4.3 Radius of influence

Radius of influence (ROI) was calculated around 4.5 m, obtained by cautiously dividing the ROI obtained with the pilot test by a safety factor of 1.3.



4.4 Off gas Treatment

Same of pilot test

4.5 Water Treatment

Same of pilot test

4.6 Control parameters

Periodic monitoring of the remediation system provided for:

- verification of the correct functioning of the system on a monthly basis;
- verification and reading of the operating parameters of the plant (flows, depressions, VOC concentrations, etc.) and possible fine-tuning, in the case of variations detected with respect to the operating parameters set;
- verification of the samples entering and leaving the water and air treatment plants on a monthly basis;
- monitoring of groundwater on a quarterly basis.

5. Results

5.1 Removal rate

The Phase 2 remediation testing activities aimed at verifying compliance with the regulatory limits of the respective environmental matrices (soil and subsoil and groundwater) or any residual contamination were carried out for groundwater and soil in 2019-2020. In particular, the following activities were carried out:

- sampling and analysis of groundwater on the entire piezometric network installed on the gas station;
- execution of 1 geognostic survey, pushed up to the maximum depth of 6.5 m b.g.s. and soil sampling and analysis.

The results of the samples taken showed full compliance with the remediation objectives for the soil, the surface aquitard and the confined aquifer.

6. Post treatment and/or Long Term Monitoring

6.1 Post treatment and/or Long Term Monitoring

Following the testing of the remediation, no further monitoring activities of the environmental matrices were carried out and in 2021 the region issued the certificate of successful remediation.

7. Additional information

7.1 Lesson learnt

In choosing the remediation technology to be adopted, the following aspects had to be taken into account:

- active fuel distribution system;
- presence of contamination in unsaturated and above all saturated soils, LNAPL and contamination in groundwater;
- technical limits of the intervention.

The environmental procedure started in 2010 was concluded in 2021 (11 years).
The remediation activities (first and second phase) and testing lasted from 2012 to 2020 (8 years).

7.2 Additional information

The keystone issue for a successful remediation is to gain a right conceptual site model, with a proper definition, in terms of extent, soil texture and presence of preferential flow pathways of the underground contamination source, in order to find adequate technology to properly address and remediate the CoCs.

7.3 Training need

E-learning/webinars in order to firstly understand the theoretical fundamentals of the technology (in terms of successful design and monitoring), but especially to be shown, through case studies, all the possible problems you can deal with during projecting, applying and monitoring the technology (lesson learnt by not perfect experiences).

Glossary of Terms

Term (alphabetical order)	**Definition**
GAC	Granular Activated Carbon
LNAPL	Light Non-Aqueous Phase Liquid
MPE	Multi Phase Extraction
P&T	Pump & Treat

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2. Site background

2.1 History of the site

Client facility in Province of Bergamo is a factory specialized in iron cabinets assembling and painting. The factory started its work in 1961 for the production of industrial shelves. In the first times, property included also the portion adjacent to the nearby river, currently owned by the Municipality. The preliminary characterization showed excedances for PCE in soils and groundwater, CHC and Metals only for groundwater.

2.2 Geological setting

Site area is made up of loose fluvioglacial deposits and colluvial soils with clayey sands, gravels and pebbles with silty and clay lenses; drainage ranges between medium and poor. The entire geological asset is extremely variable in the space of a few dozen meters. The bedrock (Dolomia) is detectable few centimetres below ground level (bgl) in NW area and at about 10 m bgl in the centre and in the eastern part of the site. We can split the area in two zones: in Zone A gravelly sands, silty clays, gravel mixed with sand and black limestone can be detected; in Zone B a distinct sequence of silt, clay, gravel, and gray limestone are identified. The depth to groundwater is approximately from 5 m to 7 m bgl detected in monitoring wells located to the eastern site boundary.

2.3 Contaminants of concern

Deep soil: PCE and Arsenic

Groundwater: Manganese, Chloroform, Vinyl Chloride, 1,1-DCE, TCE, PCE, Hexachlorobutadiene, 1,2-DCE, 1,2- Dichloropropane, 1,1,2-Trichloroethane, 1,2,3-Trichloropropane, 1,1,2,2-Tetrachloroethane, 1,2-Dibromoethane and Total hydrocarbons (mainly C5-C8 and C8-C12 detected by MADEP speciation).

Table 1. Maximum value for deep soil

Parameter	Concentration (mg/kg)
PCE	415

Table 2. Maximum values for groundwater

Parameter	Concentration (mg/l)
Chloroform	7,76E-04
Vinyl Chloride	2,33E-02
1,1-DCE	2,91E-03
TCE	2,58E-01
PCE	2,20E+01
Esaclorobutadiene	5,00E-04
1,2-DCE	6,29E-01
1,1,2-Trichloroethane	3,10E-03
1,2,3-Trichloropropane	5,00E-04
1,1,2,2-Tetrachloroethane	1,00E-03
1,2-Dibromoethane	5,00E-04
1,2-Dichloropropane	6,44E-04
Aliphatics Hydrocarbons C5-C8	1,07E+00
Aliphatics Hydrocarbons C9-C12	3,90E-02

Arsenic and Manganese are not included in this Table because they are not volatile compounds, and thus no active migration pathways were active.

2.4 Regulatory framework

Legislative Decree n. 152/2006 “Norme in Materia Ambientale” with its modifications and additions is the principal regulation for environmental characterization and remediation in Italy. Site-specific Human Health Risk Assessment (HHRA) has been developed in accordance with its content, with specific criteria and guidelines given by different Italian environmental agencies and the Ministry of Environment.

3. Pilot-scale application in field

3.1 Extraction system

- two pumps were installed in groundwater extraction wells, placed at about 1 m from the bottom of the well. The pumps were 12 V with a maximum flow of 12 L/min;
- the two pumps were connected with a manifold followed by an active carbon filter;
- in one of the wells, a lateral vacuum pump was installed with maximum flow of 100 m^3/h and maximum negative pressure of 150 mbar;
- between the well and the vacuum pump, an iron separator air/water was installed to avoid interaction with the mechanical compounds of the pump;
- air line was made up of two active carbon filters. Vapours extracted were treated and emitted in atmosphere through a chimney;
- liquid phase in the separator was released in active carbon filter by a pump;
- at the end of the process, water was collected in a 10k L tank with safety controls.

3.2 Feasibility study

The two options evaluated for the remediation of this site were P&T and MPE technologies. The choice of the MPE technology is due to:

- Enhanced groundwater flow rate recovery (more efficient than P&T);
- Enhanced radius of influence for every well than normal pumping;
- Recovering of volatile compounds from vadose zone and desaturated zone;

No explosiveness was detected.
Oxygen decrease (%) is under 1 % in the first 2 m bgl. The rate raises (over 10%) in the zone 2-4 m bgl.
CO_2 increase (%) is about 0,1 % in the first 2 m bgl. Its rate rises to 0,56 % in the zone 2-4 m bgl.
Reference values from 0,25 mbar to 4,63 mbar in the manometer are considered in order to have influence on the wells. No critical temperature was reached in the vacuum pump (only 10°C as a maximum).
Efficiency of water treatment was over 99,99 %. All the contaminants at the discharge are under detection limits for Italian Legislation. The output sampling for GAC filters showed values under detection limits.

3.3 Radius of influence

A useful parameter to measure ROI in a vacuum extraction is mounding effect (measure groundwater level increase inducted by air injection in an extraction well).

In the Table X results on Zone A are shown.

Table X: A Zone – Decrease of groundwater level with and without DPE.

Test Zone A			
Point of extraction	P2		
Extraction Flow	1 L/min (pumping only) 0.5 L/min (pumping + DPE)		
Monitoring well	**Distance (m)**	**Decrease with pumping only(m)**	**Decrease with DPE (m)**
PE4	5	0.05	0.13
P3	5	0.09	0.13
P1	9.3	0.04	0.06
P4	10	0.04	0.05

The test lasted 15 hours with a water flow of 0,5 l/min; water level was stable on extraction well and also on monitoring wells.

Analyzing data on inducted depressions, we can see possible influence from Extraction Point called P2 to Zone B (due to preferential ways).

Table Y: Daily average depressions (dP)

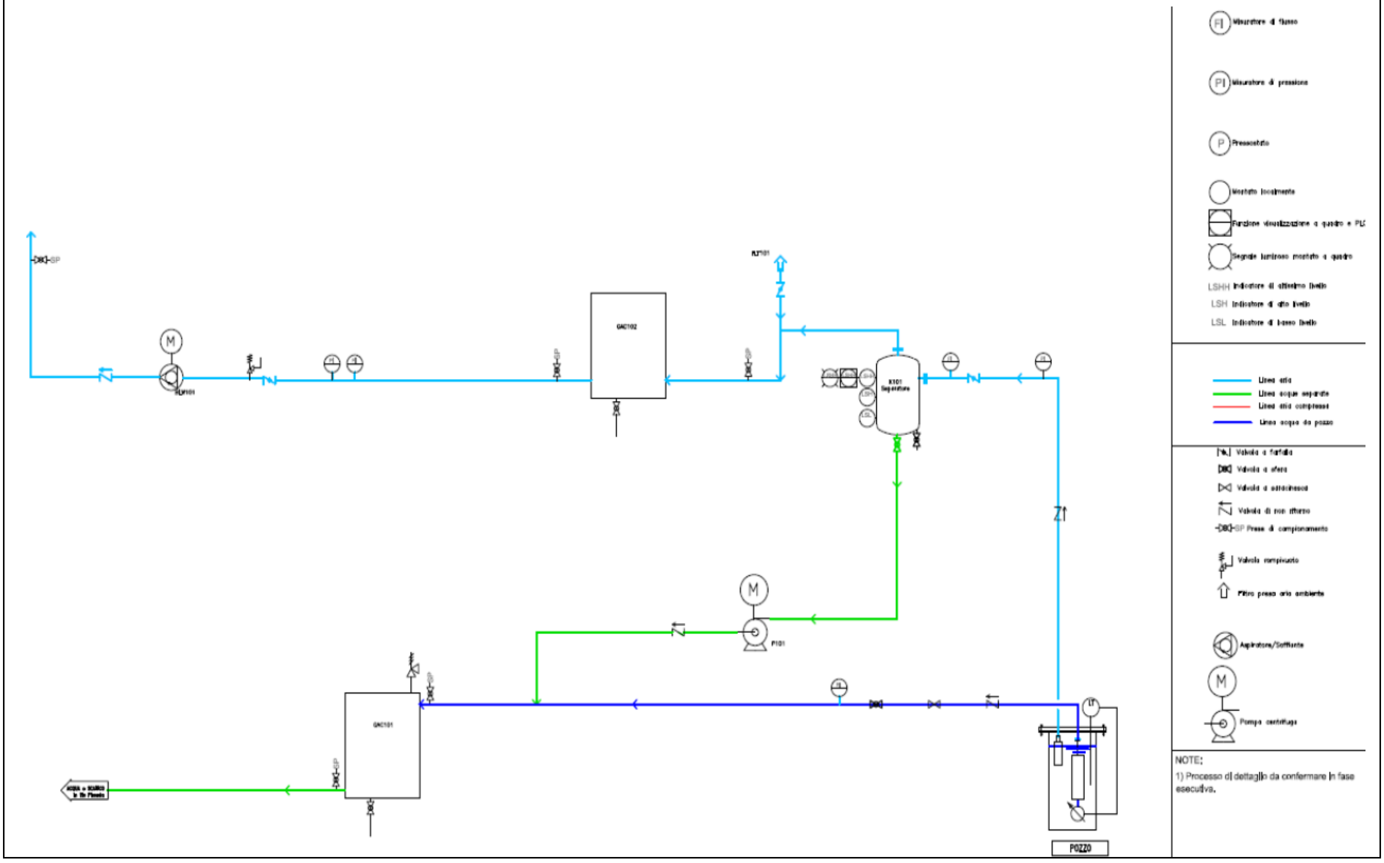
Monitoring well		**Day of DPE test**		**Distance from extraction point – P2 (meters)**
		24th of May 2018	**25th of May 2018**	
		Average inducted depression (mbar)		
A Zone	P1	5,43	0,96	9,37
	PE4	6,31	2,38	5,05
	P3	2,09	2,48	5,01
	P4	0,23	1,04	10
B Zone	P5	2,69	1,42	79
	P6	0,03	0,05	86
	PE5	0,00	0,00	91

At the end it has been decided to use a ROI of 8 m, as an average between 5 and 10 m.

3.4 Off gas Treatment

In one of the wells, a lateral vacuum pump was installed with maximum flow of 100 m^3/h and maximum negative pressure of 150 mbar; between the well and the vacuum pump, an iron separator air/water was installed to avoid interaction with the mechanical compounds of the pump; air line was made up of two active carbon filters. Vapours extracted were treated and brought out in atmosphere by a chimney;

In this case, it was calculated a contact timing of 10 seconds for air, considering PCE value of input and air flow of vacuum pump with a >90 % of adsorption on activated carbons until their exhaustion.



3.5 Water Treatment

In extraction wells, two pumps were installed, placed at about 1 m from the bottom of the well. The pumps were 12 V with a maximum flow of 12 L/min; the two pumps were connected with the manifold followed by an active carbon filter. At the end of the process, water was collected in a 10k L tank with safety controls.
For water treatment, usually the contact timing is between 10 and 30 minutes. In this case, as for the air treatment, it was calculated a contact timing of 20 minutes, considering the maximum input concentration of PCE and a >90% of adsorption rate.

3.6 Control parameters

During the test, the following parameters were monitored on the extraction wells and also in the closest monitoring wells:

- Groundwater depth
- Inducted vacuum pressure by manometer
- O_2, CO, % LEL with gas analyzer; VOCs with PID detector

A CO_2 detector was also used. Measurements were conducted at 2 and 4 m bgl in both zones A and B in order to evaluate changes.
Water contaminants compounds were analyzed by specialized laboratory: analytical set included CHCs, petroleum hydrocarbons and metals.
Air contaminants compounds were also analyzed: analytical set included only PCE compound.

4. Full-scale application

4.1 Full design system

- N.16 extraction wells, divided into 2 groups (n.10 Northern Area, n.6 Southern Area)
- N.3 monitoring wells
- N.16 pneumatic pumps
- N.1 lateral vacuum pump
- Maximum extraction flow: 480 m^3/h
- Maximum depression on the wellhead: 200 mbar
- Operative depression on the wellhead: 100 mbar
- Connection pipeline to the extraction system
- Connection pipeline from pneumatic pumps to water treatment system
- Condense separator before GAC filter for air treatment
- Oil separator, accumulation tank and bag filter for water treatment
- Water remediation system made up of n.2 GAC in-series filters
- Air treatment system made up of n.2 GAC in-series filters

All instruments, principal collectors and GAC filters have been collected in a dedicated container, acoustically isolated. Compressed air is provided by the client.
Groundwater is conveyed to treatment system by n.16 pneumatic total fluid bottom inlet pumps, in order to transport CHC, supplied by 8 bar compressed air. The pneumatic pumps have been chosen in order to respect the characteristic of the site. The piping lines have been realized above ground and are made up of pipes, connections, curves, valves, reductions, monitoring points and pressure measures. The piping and collector path has been realized in order to minimize digging operations. Air extraction needed a condense control system in order to minimize water accumulation in pipelines, in extraction system and in GAC filters.

4.2 Different areas characteristics that affect the project

The aquifer is not homogeneous: the geological asset is extremely variable in the space of a few dozen meters. This was managed in all phases of the project.

4.3 Radius of influence

The radius of influence has been determined in the pilot scale project: it has been established equal to 8 m, both for air and groundwater.

4.4 Off gas Treatment

In this project Granular Activated Carbons have been used for air treatment. Specific compounds of the air extraction system are:

- N.16 extraction wells, divided in 2 groups (n.10 Northern Area, n.6 Southern Area)
- N.1 lateral vacuum pump
- Maximum extraction flow: 480 m^3/h
- Maximum depression on the wellhead: 200 mbar
- Operative depression on the wellhead: 100 mbar
- Connection pipeline to extraction system
- Condense separator before GAC for air remediation
- Air remediation system made up of n.2 GAC filters in a series

Air extraction needed a condense control system in order to minimize water accumulation in pipelines, in extraction system and in GAC filters (280 kg each). On the pipeline, a LEL (%) sensor has been installed, with a flux meter and a sampling pump.

4.5 Water Treatment

In this project Granulated Activated Carbon Adsorption has been used for water treatment. Specific compounds of the GW extraction system are :

- N.16 extraction wells, divided in 2 groups (n.10 Northern Area, n.6 Southern Area)
- N.16 pneumatic pumps
- Connection pipeline from pneumatic pumps to water remediation system
- Oil separator, accumulation tank and bag filter for water remediation
- Water remediation system made up of n.2 GAC filters in a series

Discharge water pipeline has been realized with a HDPE 50 mm pipe, linking output GAC filters with the final point of discharge. A sampling point is just before discharging point. Remediated waters has to respect Italian surface water legal limits of Legislative Decree 152/2006 for contaminants of concern. On the discharge line there is a machanical totalizer in order to count treated water volume in output. The two iron GAC filters have been installed in-series (1500 kg of GAC each).

4.6 Control parameters

Parameters check and samples collection is performed monthly.
Activities performed periodically as follows:

- Collect sample from “In”, “Intermediate” and “out” sampling points from water GAC filters (in order to evaluate adsorption rate and avoid excedances in the output values)
- Collect sample from “In” sampling point of air GAC filters (in order to evaluate the input value)
- Check input air flow speed
- Check of vacuum pump depression and collector depression
- Check water level on monitoring wells PE2, PE3 and PE8
- Check of discharge water counter

For air sampling, the analytical set is VOC calculated on 20 normalized litres (Q= 0,5 l/min; t = 51,4 min).
For water sampling (from filters), the analytical set is made up of CHCs, metals and total petroleum hydrocarbons.
A groundwater monitoring campaign on existing monitoring wells is planned (not started yet) as follows:

- quarterly for the first 3 years
- semi-annual for further 2 years
- annual afterwards.

Analytical set includes CHC and total petroleum hydrocarbons

5. Results

5.1 Removal rate

The last summary report is dated October 2021.

The water flow rate is always under 50% of the maximum authorized flow. The air extraction system do not have a maximum authorized emission limit, as the contaminant mass flow rate is under the threshold value defined by Italian legislation (it is considered a “not-significant emission point”).

Water treatment:

- CHC: PCE input to the system in a range between 370 – 5800 µg/L. The efficiency in contaminants reduction is close to 100%. Output values are always under detection limits. The rate of CHCs input is showing a constant decreasing trend;
- Hydrocarbons: concentration input ranges between 0 and 19,3 µg/L. The efficiency of contaminants reduction is close to 100 %. The rate of hydrocarbons is constantly under detection limit in the last year;
- Arsenic and Manganese: concentration always under threshold limits;
- Mass removal of CHCs estimated in 9,1 kg from groundwater stream in the period September 2019 – August 2021 from groundwater treatment;
- PCE mass removal estimated in 400 kg of PCE from air stream in the period September 2019 – August 2021 from air treatment.

6. Post treatment and/or Long Term Monitoring

6.1 Post treatment and/or Long Term Monitoring

There is not a post treatment or long term monitoring at the moment as the remediation design has been submitted as an Operational Safety Measure.

7. Additional information

7.1 Lesson learnt

Difficulties:

- Presence of a transient aquifer, never thicker than 4 m, highly influenced by meteorological phenomena. Indeed, the average water flow rate registered is 1-2 L/min;
- Heterogeneous bedrock, with 4-5 meters variations in depth in very close wells;
- Logistic difficulties: temporary closure of the public road was required to perform operational installation of the plant.

Strengths:

- High volatile removal rate (especially PCE) particularly from the air stream;
- Excellent comprehension of the conceptual model of the site that allowed addressing these results.

7.2 Additional information

High importance of an interdisciplinary characterization for defining the best remediation technology. The following investigations activities have been performed:

- tracer test (in order to evaluate direction and speed of the groundwater flow)
- pumping test,
- boreholes,
- MIP investigation,
- groundwater monitoring,
- soil gas monitoring,
- geophysical survey (in order to outline the bedrock surface)

All these surveys allowed defining the Site Conceptual Model with high accuracy. As a consequence, locations of the pumping points were defined targeting points with specific elevation of the bedrock, maximizing the contaminants removal rate.

7.3 Training need

The best way to understand this project is the training on-the-job.
The detailed characterization performed (exposed above) aimed at refining the site conceptual model required the involvement of a wide number of different professionals with specific technical skills.
The outcome allowed engineers to define at best the remediation strategy to adopt on site, given the complex hydrogeological setting.

7.4 Additional remarks

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1. Contact details - CASE STUDY: MPE n.4

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2. Site background

2.1 History of the site

The site is located inside the Gela refinery and is a former industrial landfill used, until the 80s of the last century, for high viscous liquid waste and sludges disposal (oily waste) from refining process. It is a pool/basin with an internal footprint of about 60 x 60 m, external 80 x 80 m and a height difference between the ground level and the bottom equal to ≈ 12 m. In 2011, the removal of oily residues inside the tank was completed. In the 2013-2014, the remediation project for the unsaturated soil below the bottom of the pool was approved after requirements of the Ministry of the Environment and the public control agencies. Before the remediation activities, the perimeter of the pool was insulated with steel sheet piles and the walls waterproofed with HDPE sheets (see photo).

Site location in the south-eastern areas of Gela refinery (CL) – Italy.

The Gela Refinery areas are included in the list of Italian contaminated Sites of National Interest (SIN): for these sites, the administrative competence in remediation procedures is a responsibility of the Ministry for the Ecological Transition (MiTE).
Simam S.p.A. is the leader of the Joint Venture established with Haemers Technologies of Brussels and Icaro Ecology S.p.A. of Gela for the execution of the remediation project (2016 - in progress).

Site view, during the intervention phase with the installation of remediation systems (see Chapter 4) and Vapour Treatment Unit (upper edge of the basin).

The remediation project is based on the application of ISTD In Situ Thermal Desorption technologies with Smart Burners, patented by Haemers Technologies SA (the largest application of this technology in Europe, at the time). MPE application is a component of the remediation project and will be described below. According to the purposes of this work, ISTD technology by Smart-Burners® will not be described because the focus is on associated vapour extraction and treatment systems.

2.2 Geological setting

Site soil consists largely of silty sands interbedded with purely sand layers (from fine to medium grain size).
The depth of ground water is approximately 1,5 meters below unsaturated soil layers (-6,5 m from pool bottom ground surface).
The thickness of interest for remediation project concerns the saturated soil up to 5 m from the bottom of the basin.

2.3 Contaminants of concern

The CoCs for the soil (target of remediation projects), are represented in the summary table with average concentrations before treatment.
The concentrations are divided by intervention areas:

- Zone A (soil below the bottom of the basin);
- Zone B (soil below the strips surrounding the perimeter of the pool corresponding to the ground level of the Refinery).

Contaminants of Concern	***Zone – A (mg/kg)***	***Zone – B (mg/kg)***	***Remediation target concentrations (mg/kg)***
TPH (Total Petroleum Hydrocarbons) C≤12	*3.600*	*709*	*250*
TPH (Total Petroleum Hydrocarbons) C≥12	*19.800*	*7.723*	*750*
PAH (Polycyclic Aromatic Hydrocarbons)	*42*	*0*	*100*
Aromatic Hydrocarbons (without Benzene)	*277*	*27*	*100*
Benzene	*45*	*11*	*2*
Vinyl Chloride	*3*	*3*	*1.3*
1.2 - Dichloroethane	*49*	*2*	*0,46*
Chloromethane	*113*	*0*	*6,1*
Mercury	*11*	*20*	*-*

The remediation of unsaturated soil is the main objective of the project described in this case-study. The groundwater contamination derives from refinery activities and is widespread throughout the Gela area. The groundwater remediation

interventions/safety measures are part of a specific project, not illustrated in this case study. The groundwater safety measures are an integration of the project for unsaturated soil.
The CoCs for groundwater are:

- Total Hydrocarbons (as n-hexane)
- PAH
- Vinyl Chloride
- Organ chlorinated compounds
- Aromatic compounds
- Heavy metals

2.4 Regulatory framework

As described below, the Gela Refinery areas are included in the list of Italian contaminated Sites of National Interest (SIN). The administrative competence in remediation procedures and in authorizations for the various remediation steps is a responsibility of the Ministry for the Ecological Transition (MiTE).
The reference legislation is represented by the Italian Decree n. 152/06 "Environmental regulations" and subsequent amendments / additions.

Part IV of the Decree regulates the technical-administrative procedures/step:

- Environmental characterization of the site and identification of contaminants of concern that exceed the contamination threshold values for water and soil, defined by the Decree;
- Safety measures for soils and groundwater;
- Environmental risk analysis to define if the site is contaminated and establish any target values for remediation;
- Remediation project;
- Testing and certification (achievement of remediation target).

Each procedural step is verified and validated by the Ministry and its technical bodies and public agencies such as ISPRA (Institute for Protection and Environmental Research), ARPA (Regional Environmental Protection Agency).
Program agreements for the site between local authorities, consortia of private companies and the Ministry, can be established in relation to the specificity of the site, to define some technical-administrative aspects (e.g. natural background values) and methods of intervention.

3. Pilot-scale application in field

3.1 Extraction system

Pilot scale application in field, not foreseen for this remediation project. The treatment area has been divided into no. 2 zones: A-Zone (internal, bottom of the pool), B-zone (external). Each zone is divided, in turn, into no. 12 batch with an average surface area equal to ≈ 290 m² for A-Zone and between 228 m² and 400 m² for B-Zone (see figure in this page). Batch A1 was used, in fact, as a full scale test to verify the response of the soils and to calibrate the extraction and treatment vapour systems.

This case study does not concern the application of MPE technologies in a narrow sense but the combined application of several techniques:

- ISTD - In Situ Thermal Desorption with Gas Extraction and treatment systems;
- Dual Pump Systems (submersible pump for groundwater recovery + pneumatic submersible pump – total fluid, installed on water/oil interface). The function is to maintain the safety lowering of the groundwater level of at least 1.5 m below the unsaturated soil subject to heating up to 550 ° C.

The batches refer to single applications of thermal desorption of which the extraction of the vapour phase is an essential component.

The combination of several technologies, applied to unsaturated soils, ISTD + SVE (vapour phase) and dual pump systems for the extraction of groundwater and the removal of LNAPL, can be assimilated to an overall MPE system, and normally installed on a single well.
The combined ISTD / SVE + Dual Pump systems were applied directly full scale.

3.2 Feasibility study

In this case, the feasibility study was not foreseen, because the Ministry has decided to proceed with the direct application of the ISTD + Soil Vapour Extraction technology for the soils and groundwater.

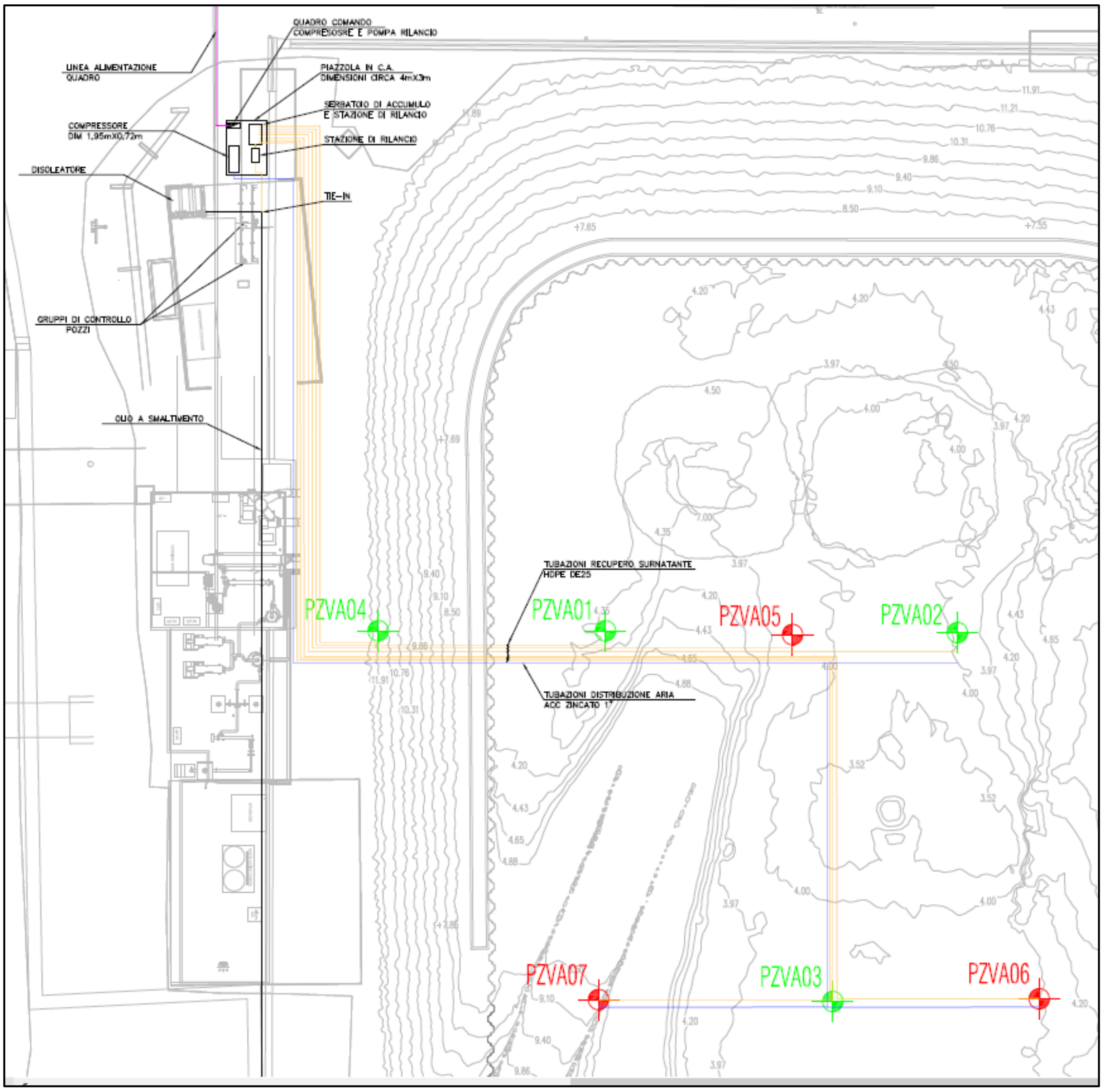
4. Full-scale application

4.1 Full design system

Components of the combined system for removing liquid phases from groundwater and vapour phase from the soil:

a) Phase liquid extraction - Dual Pump systems located at the bottom of the pool

- Submersible pump for groundwater recovery, installed on no. 7 piezometers (Ø 6’’) (PZVA01 ÷ 07) equipped with 4 '' submersible electric pumps and relaunch to the oil separation system, located close to the Vapour Treatment Unit (above the pool). Total project flow rate: 72 m^3/ day (established value to maintain the safety lowering of the groundwater level);



Dual pump wells design lay-out. This lay-out is modified based on the location of the single treatment batches to avoid interference with ISTD systems and SVE manifolds.

- Pneumatic pump/total fluid for LNPLs recovery

The process scheme provides:

- Product recovery by total fluid pneumatic pumps, top inlet, inside the existing piezometers, located at the oil-water interface level;
- Sending the product through single delivery lines to a storage tank located above the basin, near the oil separator;
- Re-launch of the product from the storage tank to the existing product delivery line (reintroduction into refinery cycles), downstream of the oil separator;
- Management systems simplified: self-regulating pneumatic pumps, air intake adjustment valve, level switch system that acts on the intake of air from the compressor, on the intake of air to the pumps, in case of too much full of the tank and on the booster pump from the storage tank;
- Dedicated power / control panel near the control panel of the groundwater pumping system.

Characteristics of the equipment

Pneumatic pumps data:

- Øext: 2’’
- minimum air flow: 3 - 4 l/min
- carbon steel casing
- pressure range: 0,4 - 9 bar

Piping:

- 1'' galvanized steel pipes for the supply of air, from the compressor unit to the wellhead;
- air intake from the wellhead to the pump, Rilsan 3/8 '' pipe (ø 9.5 mm);
- Oil delivery pipes, HDPE DE20 up to the wellhead and then DE25, PN16 for the manifold up to the storage tank.
- Valves, fittings, etc.

Electric compressor equipped with a compressed air tank (10 ÷ 13 bar rotary compressor, with 500 l tank, production: 780 l / min, 7.5 Kw, 15 HP);

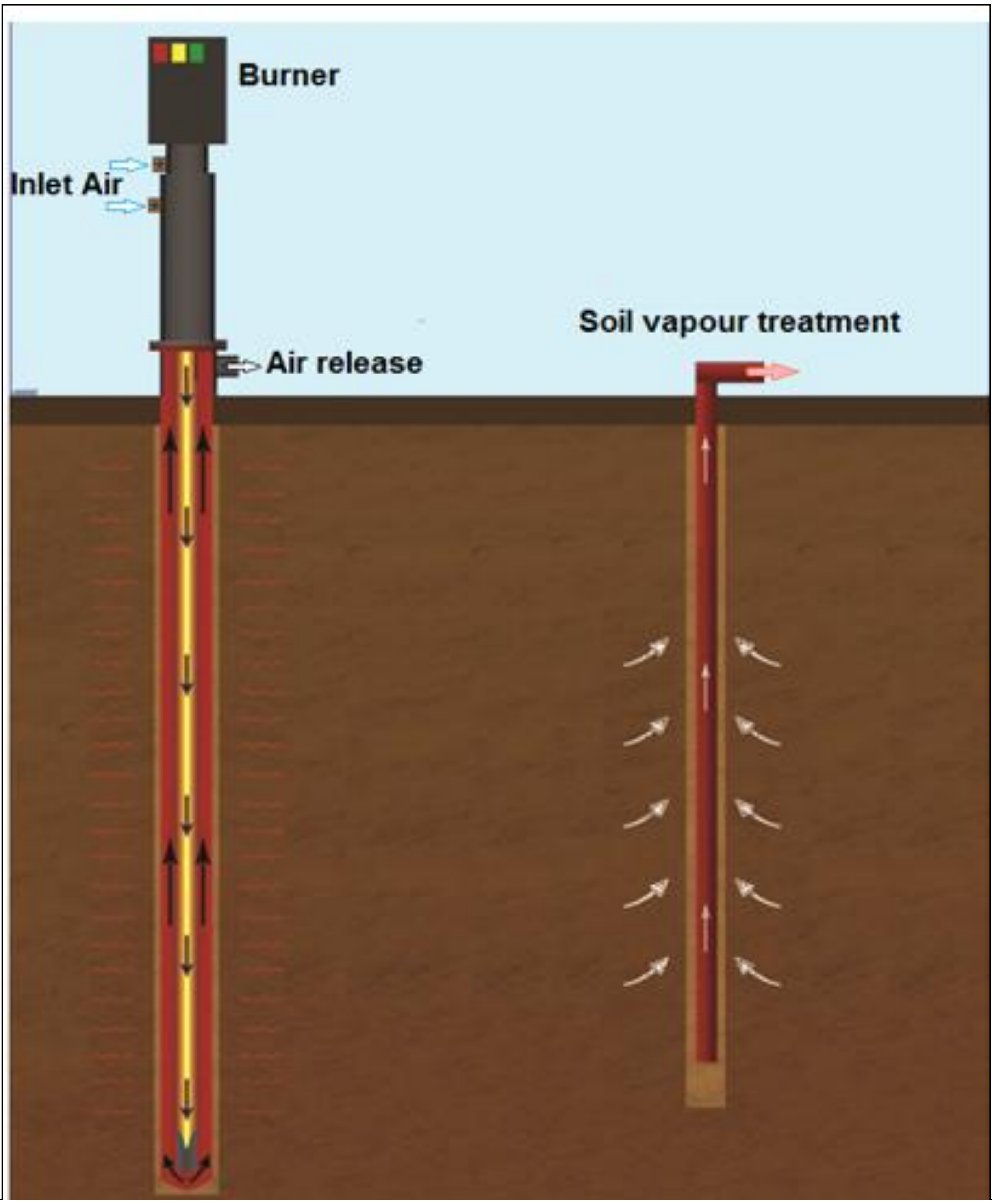
The pneumatic pumps are raised and lowered by means of winches placed on the wellhead and after having measured the water / oil interface level by means of interface probes.

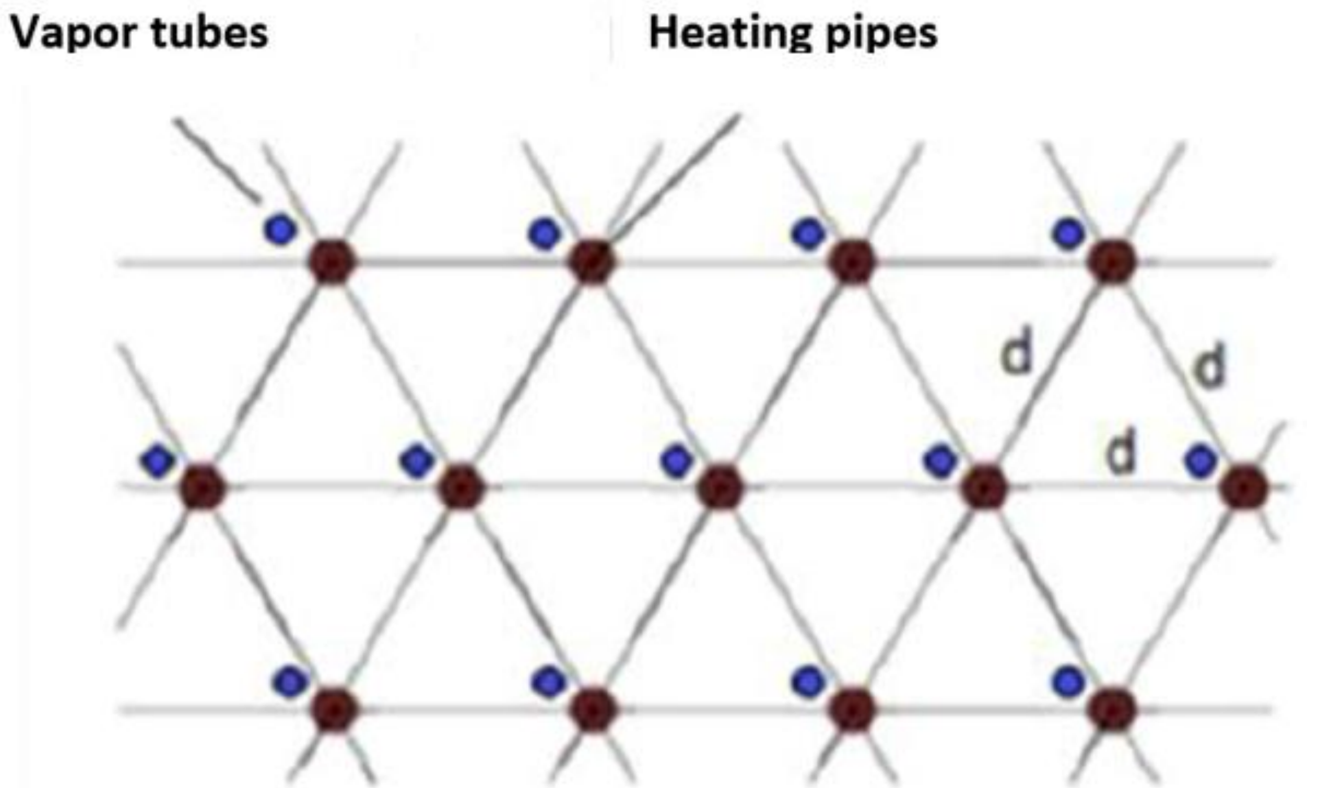
b) Phase Vapour extraction - Dual Pump systems located at the bottom of the pool

The vapour phase extraction system does not take place in the wells but uses a series of

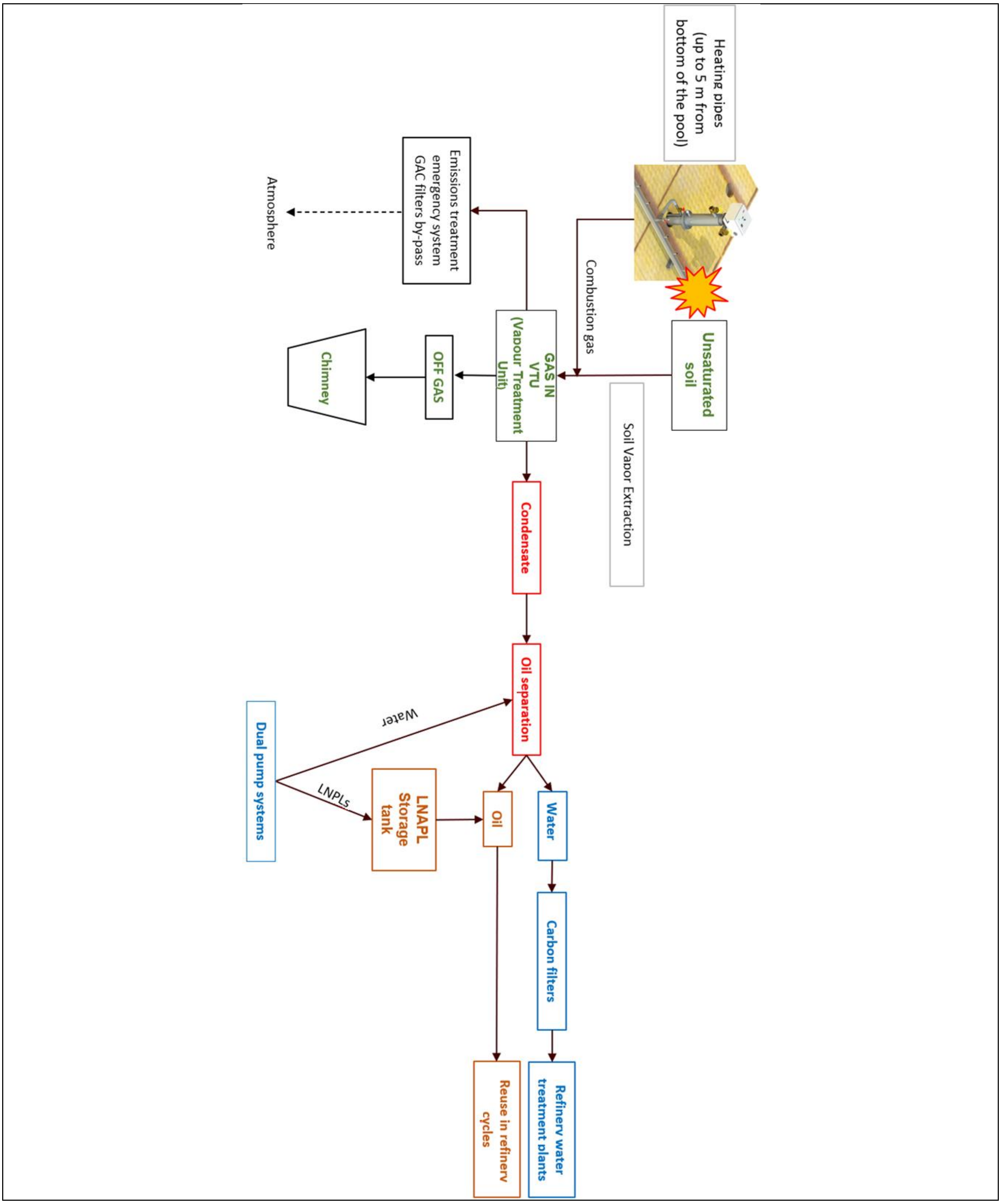
WATER AND LAND

extraction probes placed inside the individual batches near the heating tubes of the thermal desorption system (see figures), according to a grid arrangement that must cover the entire surface of the batch. The soil surface is thermally insulated by laying a concrete slab and rockwool panels.





During the heating and for the entire treatment period, the contaminants, in gas phase, are extracted by steam extraction probes, positioned in the soil, near the heating points, to then be conveyed inside stainless steel pipes and sent to the vapour treatment unit. General scheme of remediation project is in the following page.


Heating pipes
(up to 5 m from
bottom of the pool)
Unsaturated
soil
Combustion gas
Soil Vapor Extraction
GAS IN
VTU
(Vapour Treatment
Unit)
Emissions treatment
emergency system
GAC filters by-pass
Atmosphere
OFF GAS
Chimney
Condensate
Oil separation
Water
Oil
LNAPL
Storage
tank
Dual pump systems
Water
LNPLs
Carbon filters
Refinery water
treatment plants
Reuse in refinery
cycles

4.3 Radius of influence

The application of Dual Pump for extraction of phase liquid (necessary to maintain, in safe conditions, the groundwater level, 1.5 m below the unsaturated soil subjected to heating).
It was requested as integration to the project for the soil remediation, in terms of no. of wells to be installed on the bottom of the pool, single and overall flow rate of groundwater extraction functional to ensure the required lowering of the level.
The project parameters were defined by another research body (University of Rome) on the basis of the hydrogeological model of the site.
Hydrogeological modelling was not included in the aims of the unsaturated soil remediation project.

The sizing of the soil vapour extraction systems was based on:

- Volumes of soil to be treated;
- Physic-chemical characteristics of the contaminants;
- Soil characteristics (pore size, grain size, etc.);
- Vapour extraction rates.

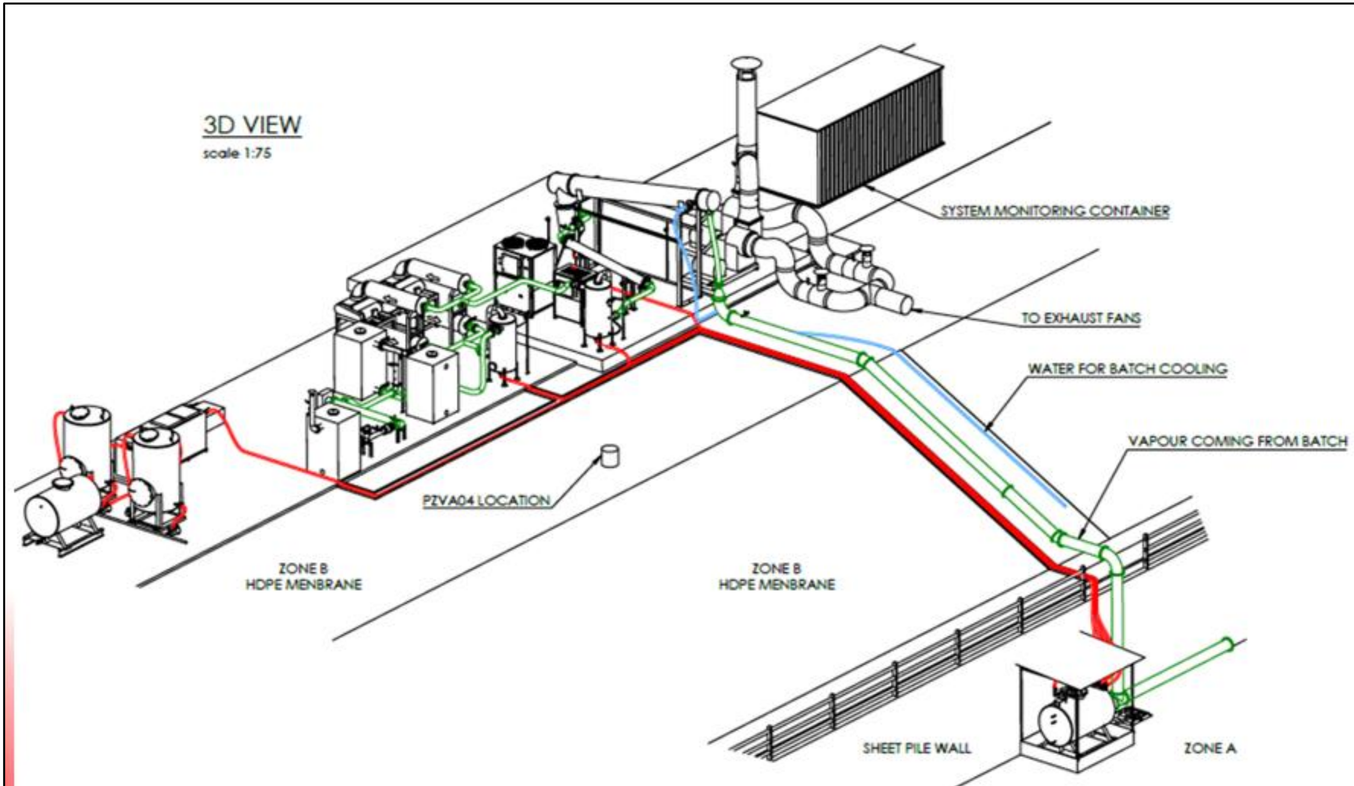
4.4 Off gas Treatment

The vapour treatment unit was installed next to basin A Zone 2. Due to the different nature of the compounds present in the extracted vapors (organic compounds, hydrocarbons, chlorinated organic compounds, mercury), it was decided to use a physical treatment system, which would allow to treat all organic contaminants and mercury by condensation of the gas extracted. This, to avoid different chemical reactions to extract the contaminants separately.
The treatment system is based on the cooling and condensation of the contaminants (operating at a temperature between 0 ° C and 5 ° C), with subsequent recovery of the same in the liquid phase (such as LNAPLs). In detail, the progressive heating of the soil causes the evaporation of contaminants and water and the destruction of part of the contaminants initially present in the soil. The vapors and gas produced are extracted by primary / secondary pipes of the SVE system and sent to a first heat exchanger with condensate collection. Subsequently, the circuit includes a second heat exchanger and a cooling unit (Chiller / Cooler).
The cycle continues with the passage through a regenerative absorber (catalyst) and

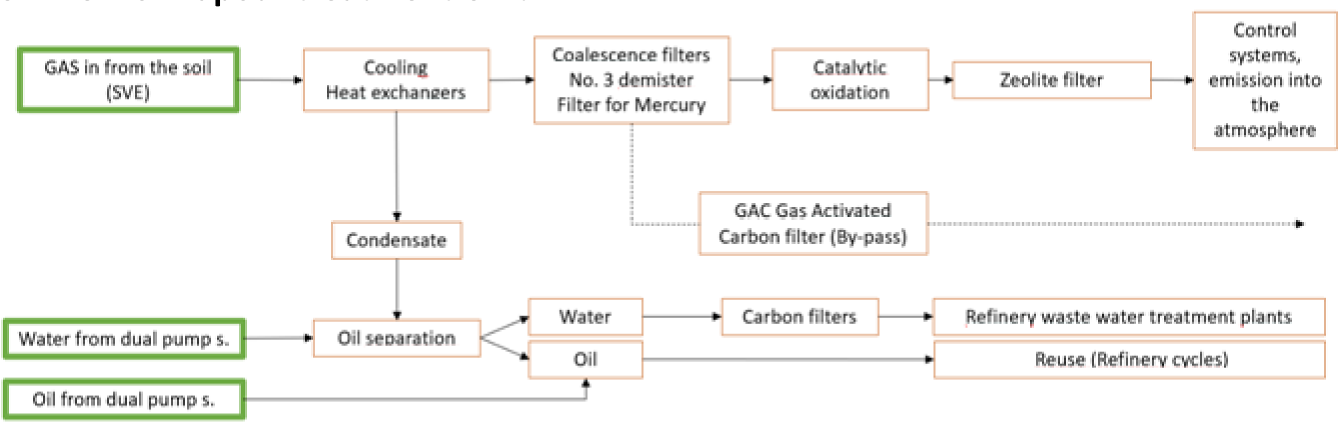
zeolitic carbon filters and from here to the chimney with a system for controlling the gas emission parameters into the atmosphere.

An additional treatment section was also installed on the by-pass of the main circuit, consisting of n. 2 filter boxes with GAC (Granular Activated Carbon Filter), to be used in case of emergency and / or maintenance of the main circuit, with the need to by-pass the flow.

Two blowers, placed in parallel with each other, ensure the depression in the soil and are a reserve to the other during the treatment of the batch.



3D view of Vapour treatment Unit

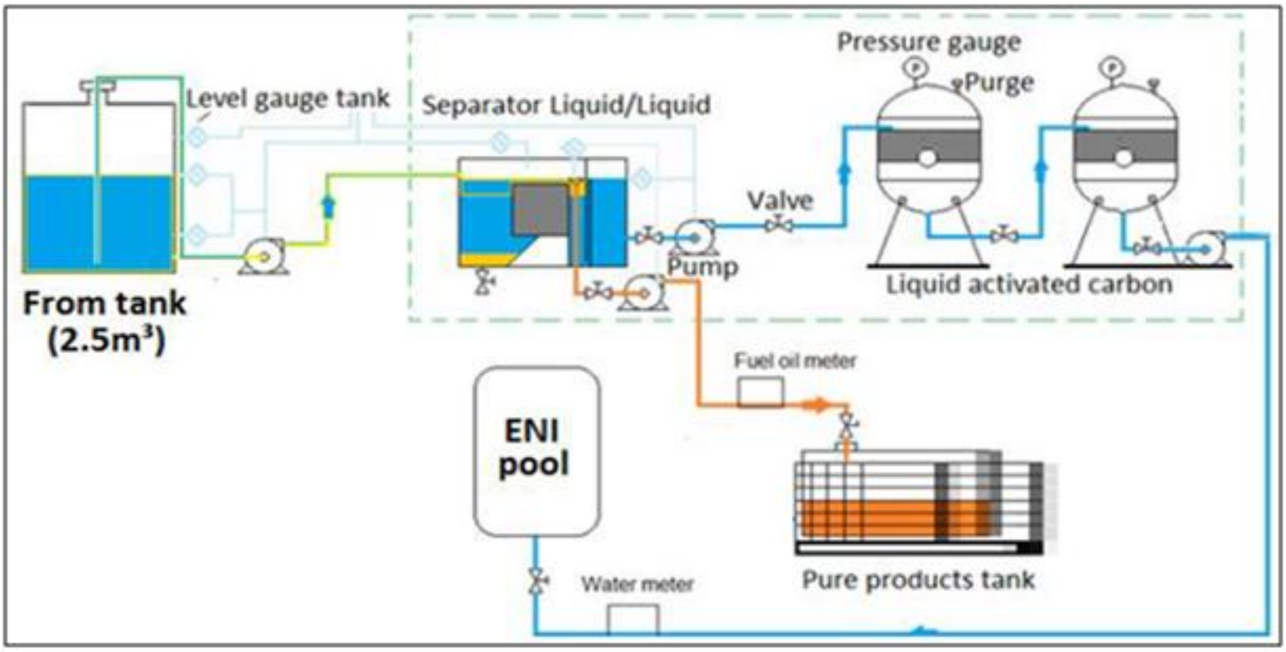


General scheme of liquid and vapour phase extraction and treatment

4.5 Water Treatment

The effluent (water from dual pump systems and condensate from vapour treatment unit, after oil separation) go to an existing refinery groundwater and wastewater treatment plants. The battery limit of MPE treatment is the delivery point of the water to the refinery piping network which collects all the water coming from the groundwater remediation and safety measures systems (hydraulic barriers).

The water, before being transferred to the treatment plant, are subjected to oil separation and passing over carbon filters, as shown in the following diagram (ENI Group is the Client/Owner of Refinery):



4.6 Control parameters

Field monitoring and sampling program that will adequately monitor the effectiveness of the treatment. As for example:

- Contaminant concentrations in groundwater compliance with the acceptability criteria of input parameters to the treatment plant;
- Oxygen, carbon dioxide, carbon monoxide, TOC, contaminant concentrations in SVE in-gas e off-gas or soil vapour;
    - continuous analyzers (in gas and off gas)
    - lab analyzes (daily) also with sampling from the probes on the ground
- Multilevel soil temperature;
- Air flow and extraction rates;
- Air pressure measurements;
- Water and oil levels (dual pump systems);
- Daily volumes of water discharged, condensates and oil recovered and progressive values from the start of remediation.

5. Results

5.1 Removal rate

It is not possible to define an efficiency value of the applied techniques since they must be verified considering the remediation target (residual concentrations of CoCs in the soil) and compliance with the legal limits required for the gas emission into the atmosphere. In this case, good contaminant removal efficiency can be defined, after soil analysis. The qualitative monitoring of In gas e off gas also allows to define the quantities of recovered contaminant and the recovery and vapour treatment efficiency, for each remediation batch. The efficiency of the treatment is also measured by verifying the degree of consumption of the filters and the trend of the parameters of the off gas, analyzed on the chimney. The parameters must comply with the legal limits, otherwise the system must be switched off to avoid the introduction of contaminants into the atmosphere. A system of by-pass filters makes it possible to carry out maintenance operations on the treatment system with autonomy of a few hours. As regards dual pump systems, the degree of recovery efficiency is measured through the volumes of water and LNPLs emitted and the maintenance of water levels, below the safety limit, and the LNPL thickness tending to 0.

The contaminants removal and treatment good efficiency, for each batch is based on following assumption:

- The temperature of 250 ° C has been reached - decisive criterion for switching off the heating system and start with cooling phase, before soil sampling;
- The temperature reached and the removal of the contaminant mass were also confirmed by the results of the monitoring of the concentrations in the condensates and in the vapors extracted from the soil;
- The average for the period, referring to the soil vapour extraction points, showed a general trend in concentrations consistent with that of temperature;
- The analysis of the parameters referring to emissions into the atmosphere and those of mass flows did not show that the regulatory thresholds were exceeded.

One of the criteria for establishing the achievement of the soil remediation target for a batch is the asymptotic trend of gas concentrations (maximum level of efficiency in gas extraction from the soil).

The main criterion is the achievement of temperatures of 250 ° C in the soil for at least 5 days, in the "cold" points, i.e. those furthest away from the heating pipes.

Temperature monitoring is also performed by thermocouples installed in the soil at different depths. The data is managed by a PLC with pc and dedicated software application.

6. Post treatment and/or Long Term Monitoring

6.1 Post treatment and/or Long Term Monitoring

After soil heating and during the cooling phase (vapour phase)

- Soil temperature trend
- Oxygen, carbon dioxide, carbon monoxide, TOC, contaminant concentrations in SVE in-gas e off-gas or soil vapour ;
- continuous analyzers (in gas and off gas)
- lab analyzes (daily) also with sampling from the probes on the ground
- Multilevel soil temperature;
- Air flow and extraction rates;
- Air pressure measurements;
- Water and oil levels (dual pump systems);
- Daily volumes of water discharged, condensates and oil recovered and progressive values from the start of remediation.

The extraction of vapors from the soil continues even during the cooling phase to avoid emissions from the ground and limit the rebound phenomena due to the presence of contaminants in the ground that have not yet been stripped by thermal desorption and SVE.

Once the soil has reached temperatures <70 ° C, soil sampling and analysis will be carried out to verify the residual concentrations and the achievement of the remediation target.

Dual pump systems

The operation of the dual pump systems proceeds in continuous even at the end of the heating of the soil and during the passage from one batch to another. The parameters are the same as already indicated in the point 4.6.

7. Additional information

7.1 Lesson learnt

1) Methodology and procedures

The procedures and methodologies are those codified in the final approved project, therefore an attempt was made to improve the design aspects in the development of detailed engineering and in the conditions of applicability, especially in relation to gas treatment systems. One of fundamental aspects regarding the lessons learnt concerns the response of the remediation and treatment systems in relation to the actual characteristics of the site, not foreseen in the approved project, especially in terms of concentrations of major pollutants, or heavy hydrocarbons, more difficult to remove and to be treated.

2) Technical aspects
What indicated in the previous point has translated into progressive technical improvements, especially after batch 1 which represented the full-scale pilot batch. It is important to underline that these methodologies had never been applied on a large scale in Italy. The lesson learnt on the technical aspects concerned the upgrading of the treatment system and the optimization of the consumption of electricity and methane to power the burners and treatment systems. Main difficulties: technological limit in the extraction of contaminants consisting of heavy hydrocarbons (concentration values higher than the project data), heterogeneity in the characteristics of the soil within the same batch, constant maintenance of the control systems (gas analyzers). Lesson learnt:

- Implementation of the vapour treatment system and efficiency enhancement;
- Increase VTU and batch monitoring points;
- Modification of PLC and control systems;
- Hot sampling preliminary to final testing (creation of procedures for soil sampling and analyzing in condition of high temperatures to define, before official testing and cooling, the effectiveness of the treatment and any extension, even in zones, of the heating with vapour extraction.

3) legislative, organizational aspects
The legislative aspects are fundamental: respect for the target values of the reclamation and respect for the legal values for the emission into the atmosphere. This entailed a significant economic commitment in organizational terms (multidisciplinary figures for data and plant management) and analytical control systems. The efficiency of remediation is verified by acceptance tests with the environmental agencies, therefore the improvement of the control systems on the progress of the remediation was important to avoid the repetition of the batch treatment with additional financial charges.

7.2 Additional information

Mainly, as already mentioned in the previous point, the answer is in the most in-depth verification of the actual state of the site and the characteristics of the land, to limit the need for extraordinary maintenance, changes in the execution phase of the treatment systems and evaluate more precisely energy consumption.

7.3 Training need

Regard to the training needs from the technical, procedural, organizational point of view practical experience has allowed to define some fundamental points (some of them are applied in the executive phase):

- Internal periodic technical meetings for sharing activities, critical issues and management data analysis by the various figures (HSE Manager, Environmental Engineer, site manager, project structures, analysis of purchases and management costs, etc.);
- Webinar on ISTD and MPE application, with sharing of activities and presentation of applications in different sites at European level;
- Internal staff competence audits with proposals to improve staff preparation (e-learning from the company headquarters).

7.4 Additional remarks

In this case, the application of MPE technologies was considered in a broader perspective of combined remediation techniques applied on the site and not within a single well. So, an important aspect is that the site approach should consider the strengths and weaknesses of the individual technologies and evaluating their integrated efficiency.

Glossary of Terms

Term (alphabetical order)	**Definition**
C	Carbon (number of atoms)
CoCs	Contaminants of Concern
GAC	Granular Active Carbon
HDPE	High Density Poly Ethylene
ISTD	In Situ Thermal Desorption
LNAPL	Light Non Aqueous Phase Liquid
MPE	Multi-phase extraction
PAH	Polycyclic aromatic hydrocarbons
PLC	Programmable Logic Controller
SVE	Soil Vapor Extraction
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
VOC	Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature
VTU	Vaport Treatment Unit

1. Contact details - CASE STUDY: MPE n.5

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2. Site background

2.1 History of the site

Former automotive production Site in Italy, currently dismissed. In the so-called “Reparto Segmenti” Area, significant impacts due to chlorinated solvents were identified in groundwater.

2.2 Geological setting

The stratigraphy of the Site, up to 20 m from ground level, consists of:

- Local levels of backfill soil (sand or gravel), with thickness generally varying between 1.5 and 2 m;
- A layer of sediments of lacustrine origin (sandy clays and/or silty clays), up to a maximum depth of approximately 20 m from the ground surface.

Groundwater is present in both layers, but extraction rates are limited given the abundance of fine materials. Dept-to-water values are in the order of 1-2 m bgl

2.3 Contaminants of concern

Mainly Trichloroethene (TCE) and daughter products (dichloroethylene and vinyl chloride), with concentrations up to 963,000 µg/l, 9,840 µg/l and 823 µg/ before remediation, respectively.

The greatest mass of halogenated compounds is located at depths between 1 and 6 m from the surface (based on the results of a Membrane Interface Probe survey) in the "Reparto Segmenti" area.

2.4 Regulatory framework

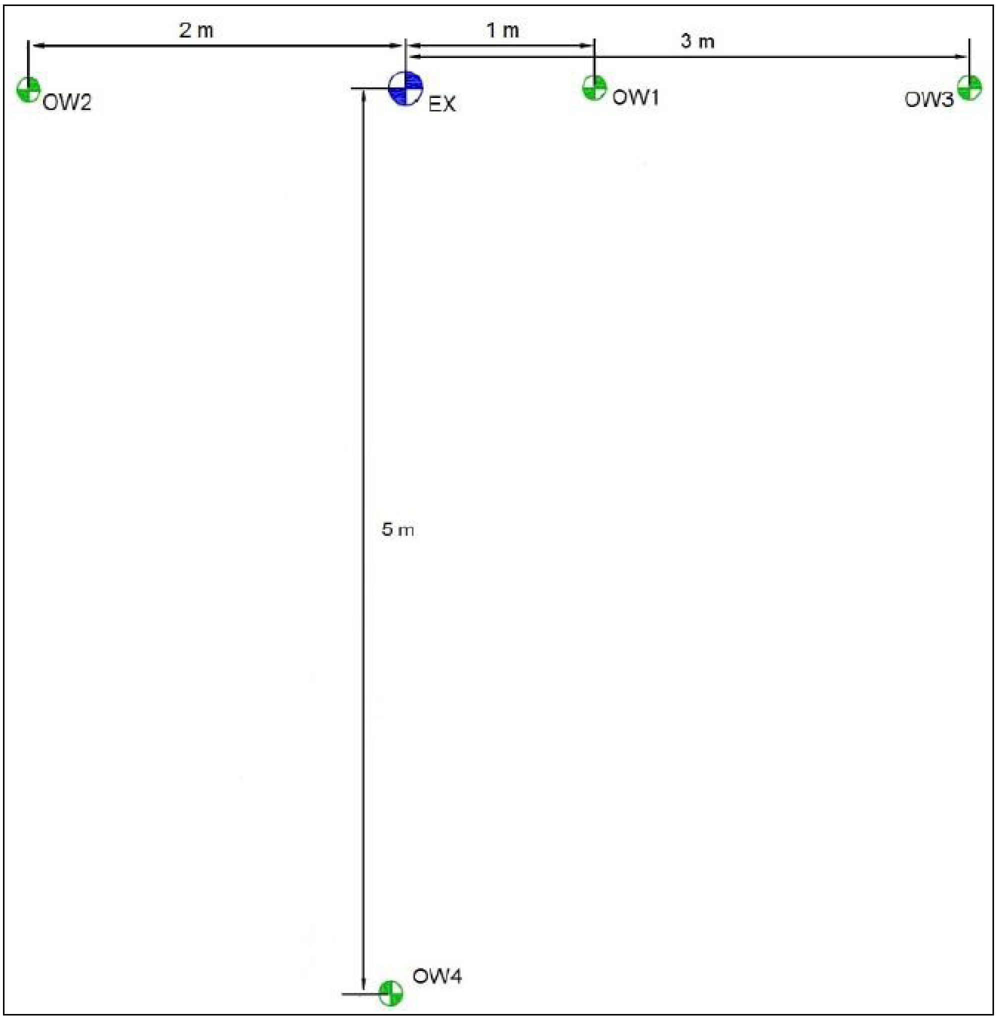
The screening concentrations set by the Italian legislation for groundwater (CSCs, e.g. 1.5 µg/l for trichloroethylene) were exceeded. A site-specific risk assessment was submitted to the Authorities and approved, resulting in less conservative risk-based remediation goals (CSRs, e.g. 1,500 µg/l for trichloroethylene). Since the detected concentrations in groundwater were above the CSRs, a remediation design (based on the application of Multi Phase Extraction technology) was presented to the Authorities and approved.

3. Pilot-scale application in field

3.1 Extraction system

The MPE system used for the pilot test consisted of four main components:

- MPE extraction well (EX, installed within the most impacted area, PVC, 4", 6.05 m deep, screened 1 – 6 m bgl;
- 3 monitoring wells (OW1, OW2, OW3, at distances respectively 1, 2 and 3 m from the extraction well) made of 3" PVC, 6 m deep, screened 1 – 6 m, used to monitor pressure variations in both the saturated and unsaturated zone;
- 1 monitoring well piezometer (OW04), 1" PVC, 1.3 m deep, screened 0.5-1.3 m bgl, used to monitor pressure variations within the unsaturated zone;
- MPE extraction and treatment unit (ECOVAC mobile plant, consisting of a vacuum pump, air/water separator, activated carbons for vapours and a tanker for water);
- -Extraction piping (from the MPE wells to the MPE treatment unit).



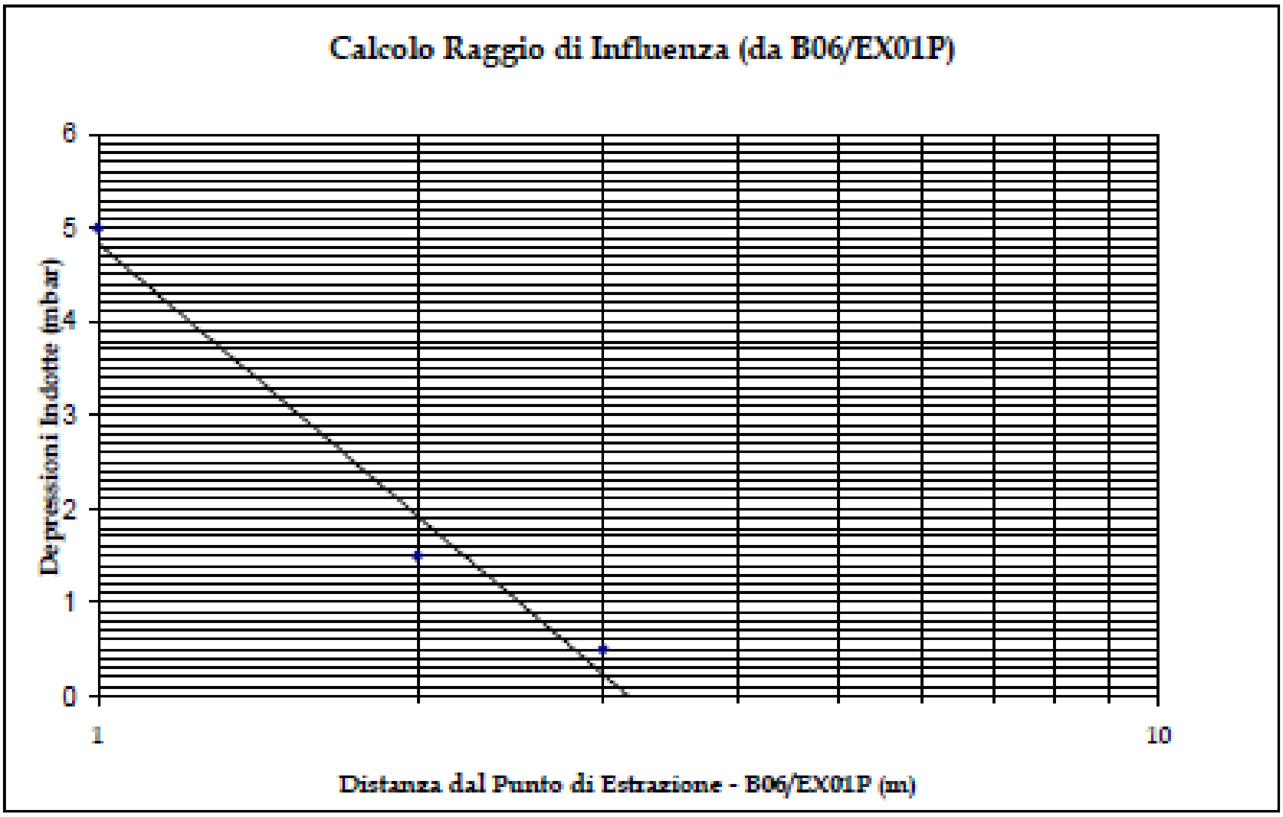
3.2 Feasibility study

During the on-site testing activities, field measurements were carried out for parameters such as: vacuum at the blower, vacuum generated in the unsaturated zone, hydrostatic responses, concentrations of contaminants in the extracted vapors and liquids, vapour and water extraction rates.

3.3 Radius of influence

On the basis of the data from the OW monitoring wells, it was possible to estimate the site-specific radii of influence:

- Hydraulic radius of influence (in the saturated zone) exceeded 3 m;
- Radius of influence for vapour extraction (in the unsaturated zone) was 3 m.



The graph shows that the vacuum induced by the extraction system in the unsaturated zone reaches zero at a distance of about 3 m. Consequently, the radius of influence of the system was set equal to 3 m.

3.4 Off gas Treatment

2 m^3 activated carbon vessel filled with 1200 kg of granular activated carbons. Extracted vapors were treated by means of activated carbons before discharge to the atmosphere. Extracted liquids were stored and disposed of.

3.5 Water Treatment

No water treatment was implemented. Water collected in the air/water separator was stored, properly characterized and disposed of.

3.6 Control parameters

Vacuum at the blower, vacuum generated in the unsaturated zone, hydrostatic responses, concentrations of contaminants in the extracted vapors and liquids, vapour and water extraction rates

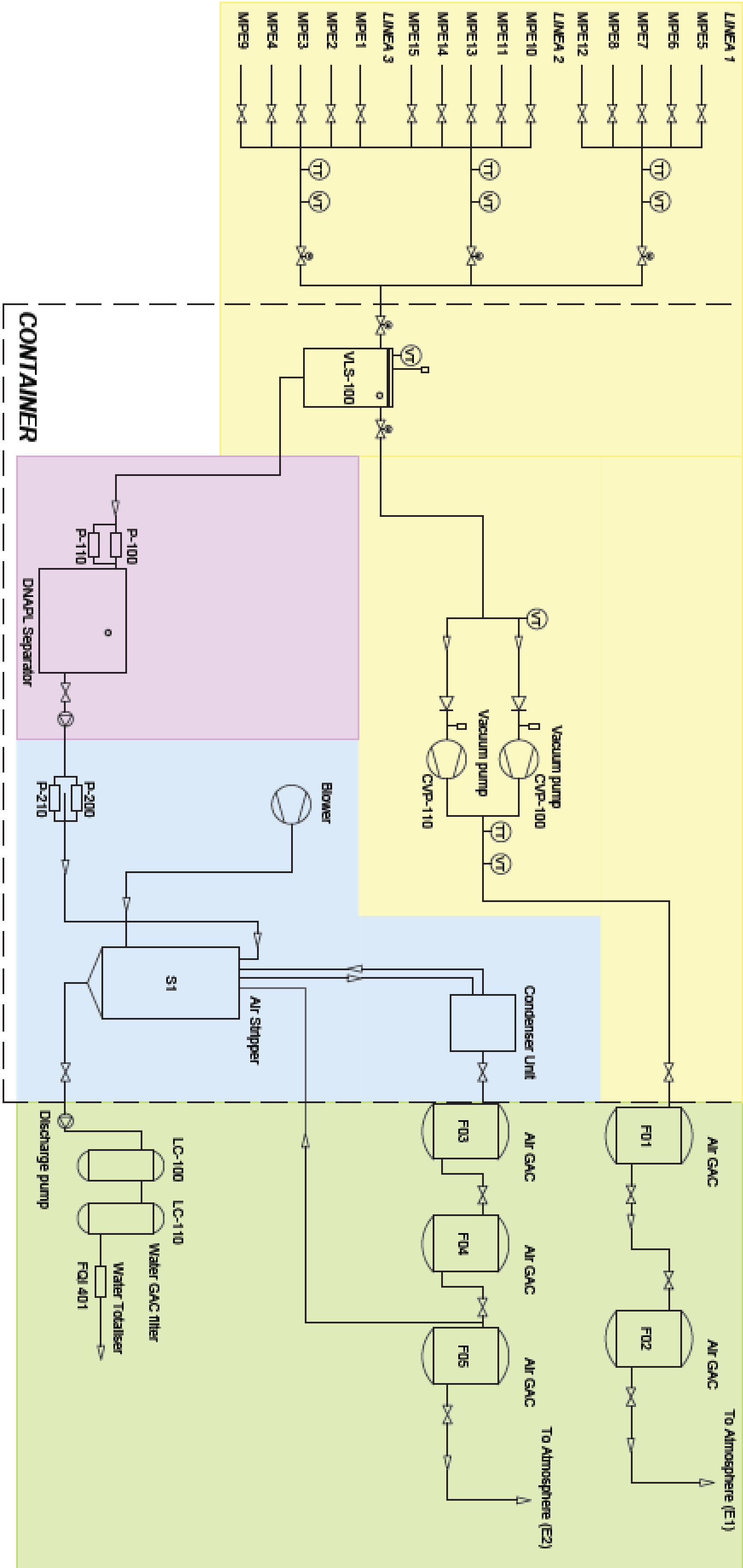
4. Full-scale application

4.1 Full design system

- <u>the number and characteristic of extraction system in the full scale application</u>

The full scale system consisted of 15 6m-deep, 6" diameter extraction wells (screened 2-6 m bgl) connected to two vacuum pumps (max vacuum 750 mbar, max extraction rates 200 Nm^3/h). A slurper was installed in each well. Three extraction lines, each connecting 5 extraction wells, were realized, in order to allow "pulse" extraction from different lines.

A water/vapour separator was installed before the blowers. Water was sent to a DNAPL separator, treated by means of a stripper (for preliminary treatment of extracted GW) and then by means of activated carbons before discharge. Vapors (extracted form subsoil or stripped during water treatment) were treated by means of activated carbons before discharge (or re-use in the water treatment process).


LINEA 1
MPE5
MPE6
MPE7
MPE8
MPE12
LINEA 2
MPE10
MPE11
MPE13
MPE14
MPE15
LINEA 3
MPE1
MPE2
MPE3
MPE4
MPE9
TT
VT
VLS-100
CONTAINER
P-100
P-110
DNAPL Separator
Vacuum pump
CVP-100
Vacuum pump
CVP-110
Blower
P-200
P-210
S1
Air Stripper
Condenser Unit
F01
Air GAC
F02
Air GAC
F03
Air GAC
F04
Air GAC
F05
Air GAC
To Atmosphere (E1)
To Atmosphere (E2)
LC-100
LC-110
Water GAC filter
Water Totaliser
FQI 401
Discharge pump

4.2 Different areas characteristics that affect the project

Not applicable. MPE application was equal throughout the entire treatment area.

4.3 Radius of influence

Not applicable. The radius of influence was not re-estimated during the full scale operations

4.4 Off gas Treatment

A water/vapour separator was installed before the blowers. Vapors (extracted from subsoil or stripped during water treatment) were treated by means of activated carbons before discharge (or re-used in the water treatment process).

4.5 Water Treatment

A water/vapour separator was installed before the blowers. Water was sent to a DNAPL separator, treated by means of a stripper and then by means of activated carbons before discharge.

4.6 Control parameters

Vacuum at the blower, vacuum generated in the unsaturated zone, hydrostatic responses, concentrations of contaminants in the extracted vapors and liquids and after their treatment before discharge, vapor and water extraction rates. These parameters were measured every week (for the first three months) and then every 15 days. Groundwater/soil gas samples at extraction wells were teken every 4 months.

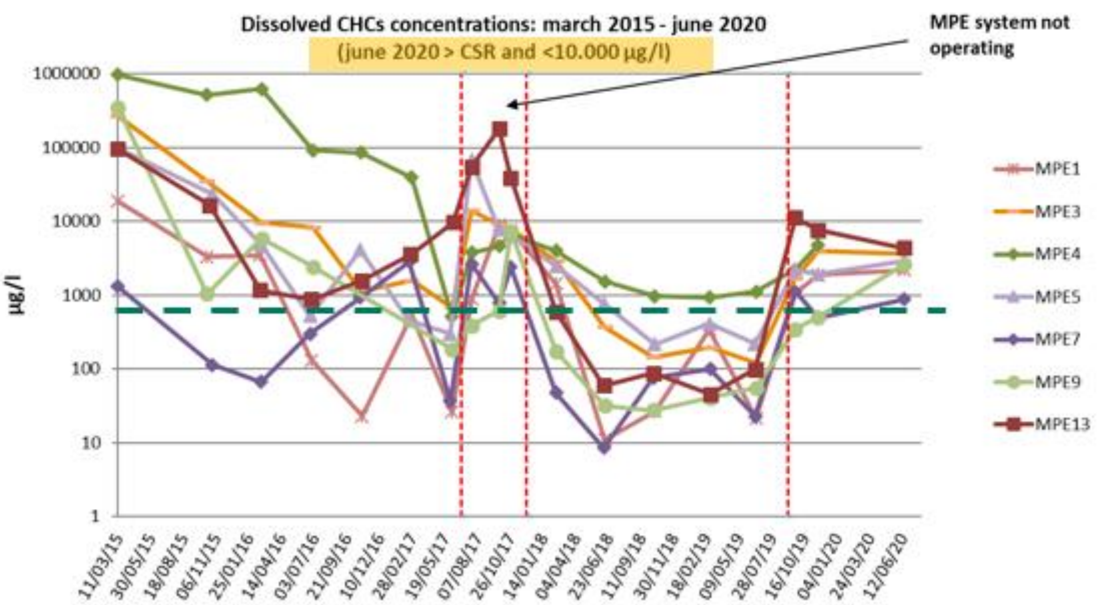
5. Results

5.1 Removal rate

The mass of chlorinated solvents extracted with MPE system after 4 years of operation (2015 – July 2019) was as follows :

- about 6 kg of chlorinated compounds (CHCs) extracted as dissolved phase
- about 278 kg of CHCs extracted as vapors

In 2019 the MPE was shut-off, after achieving its technological limit (the cumulative recovered mass reached an asymptotic trend). Comparing the dissolved concentrations in groundwater before and after the remediation phase, an average decrease of about 70% was registered.



6. Post treatment and/or Long Term Monitoring

6.1 Post treatment and/or Long Term Monitoring

- After MPE shutdown, two monitoring campaigns were conducted, one at the end of September 2019 and the other in November 2019 to verify concentration rebound (leading to the average remediation performance value of about 70% reported in the previous section);
- Since November 2019, one monitoring campaign has been performed every year.
- Every six months (June and December): sampling and analysis of ambient air.

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1.7 Phone number	

2. Site background

2.1 History of the site

The site is a former industrial pharmaceutical plant of about 30.000 m2, located in a central area of a small town in Northern Italy. The plant remained active until 1980, and then was used as a warehouse until 1996, when environmental investigations carried out found the presence of contamination in soils and groundwater for compounds such as: Benzene, Toluene, Monochlorobenzene and Trichloromethane.

2.2 Geological setting

The subsoil presents a first superficial layer constituted by soils and backfill materials, in some areas present up to about 2 meters from the ground level, followed by a frequent alternation in vertical and horizontal sense between fine lithotypes (mainly silty) and coarser and more permeable lithotypes (mainly sands and silty sands) up to the first 7-8 meters of depth.

From this depth, a clayey layer is present up to about 32 meters above ground level, which constitutes the basal impermeable level of the surface aquifer.

An exception is the south-western portion of the site where the presence of permeable materials with a sandy-gravel matrix has been detected between 7-8 meters from the surface and about 15 meters from the surface, which implies a subdivision of the surface aquifer into two levels (surface horizon and deep horizon). Below this level there is the clayey layer up to about 32 meters from the surface level detected in the other sectors, which constitutes the basal impermeable level of the surface aquifer also in this sector.

The subjacent level of the surface water table is between -1 and -2 m from ground level.

Beginning at 33 to 42 m from w.g. is the first confined deep aquifer.

2.3 Contaminants of concern

- Benzene (maximum concentration 3.500 µg/l average concentration 550 µg/l)
- Monochlorobenzene (maximum concentration 53.000 µg/l, average concentration 3.300 µg/l)
- Other contaminants: Trichloromethane (average concentration 1,2 µg/l)

2.4 Regulatory framework

Remediation with MPE is a part of the interventions planned for the site, which also includes the use in other areas of different remediation technologies such as Dig&Dump of unsaturated contaminated soil, in situ thermal desorption, on-site soil treatment by SVE, ISCO and Pump&Treat.
With regard to the remediation with MPE system planned for the groundwater in the central area of the site, object of this case study, the approved remediation objectives are the CSR calculated through the site specific risk assessment procedure (benzene 310 µg/l, monochlorobenzene 5.300 µg/l).

3. Pilot-scale application in field

3.1 Extraction system

The test field included an extraction point and 5 monitoring points located at distances between 2 and 9 m from the extraction point. Each point consists of a 4" diameter well with a screened section starting from the groundwater level (2.0 m b.g.s.) to the bottom of the hole (7 m b.g.s.).
The suction of groundwater and vapors was performed using an ATEX vacuum pump that can generate depressions greater than 900 mbar.
A wellhead was attached to the extraction well to which a slurper consisting of 1" HDPE piping was directly connected.
A condensate separator was connected to the pump to allow separation of groundwater and sediment from the extracted vapors.

3.2 Feasibility study

MPE was found to be effective for contaminant removal in areas just outside of source areas, where thermal treatment was not conveniently applicable for economic and logistical reasons. While LNAPL/DNAPL is not present, the technique was deemed suitable for physical removal of contaminants in the saturated soil given their volatility. The low permeability of groundwater (2x10-7 m/s) also allows significant lowering of groundwater levels, thus facilitating vapour extraction in the desaturated section up to a thickness of 3 meters. The assumptions were confirmed by both the pilot test and the full-scale operation of the system, which showed significant gas-phase contaminant recovery rates, especially in conditions of greater groundwater lowering.

3.3 Radius of influence

Radius of influence (ROI) of the system was calculated by performing a pilot test with steps of increasing vacuum. Considering a vacuum of 500 mbar in the extraction well, radius of influence (ROI) was calculated around 5 meters on the basis of induced vacuum. A drawdown of 0,25 mbar was considered as the boundary of the effect of the well. During the pilot test, the induced lowering of the water table was also measured, which was more than 2,5 m at a distance of 2 m from the extraction point and 1,3 m at a distance of 5 m.

3.4 Off gas Treatment

Vapours extracted during the pilot test were treated through a battery of activated carbon filters installed in series.

3.5 Water Treatment

The liquid effluent goes to an existing groundwater treatment plant.

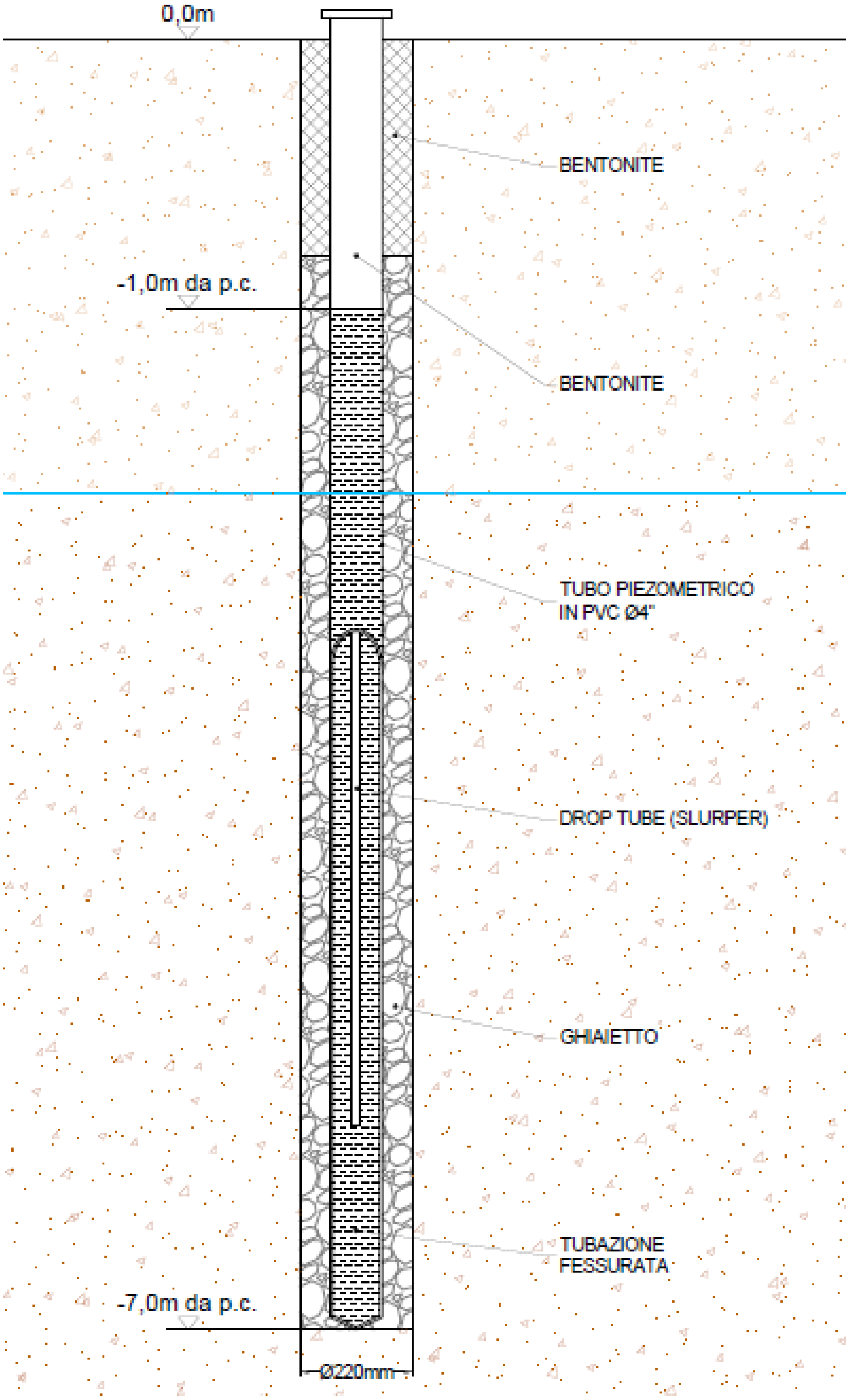
3.6 Control parameters

During the pilot test, the data necessary to design the full-scale system were collected:

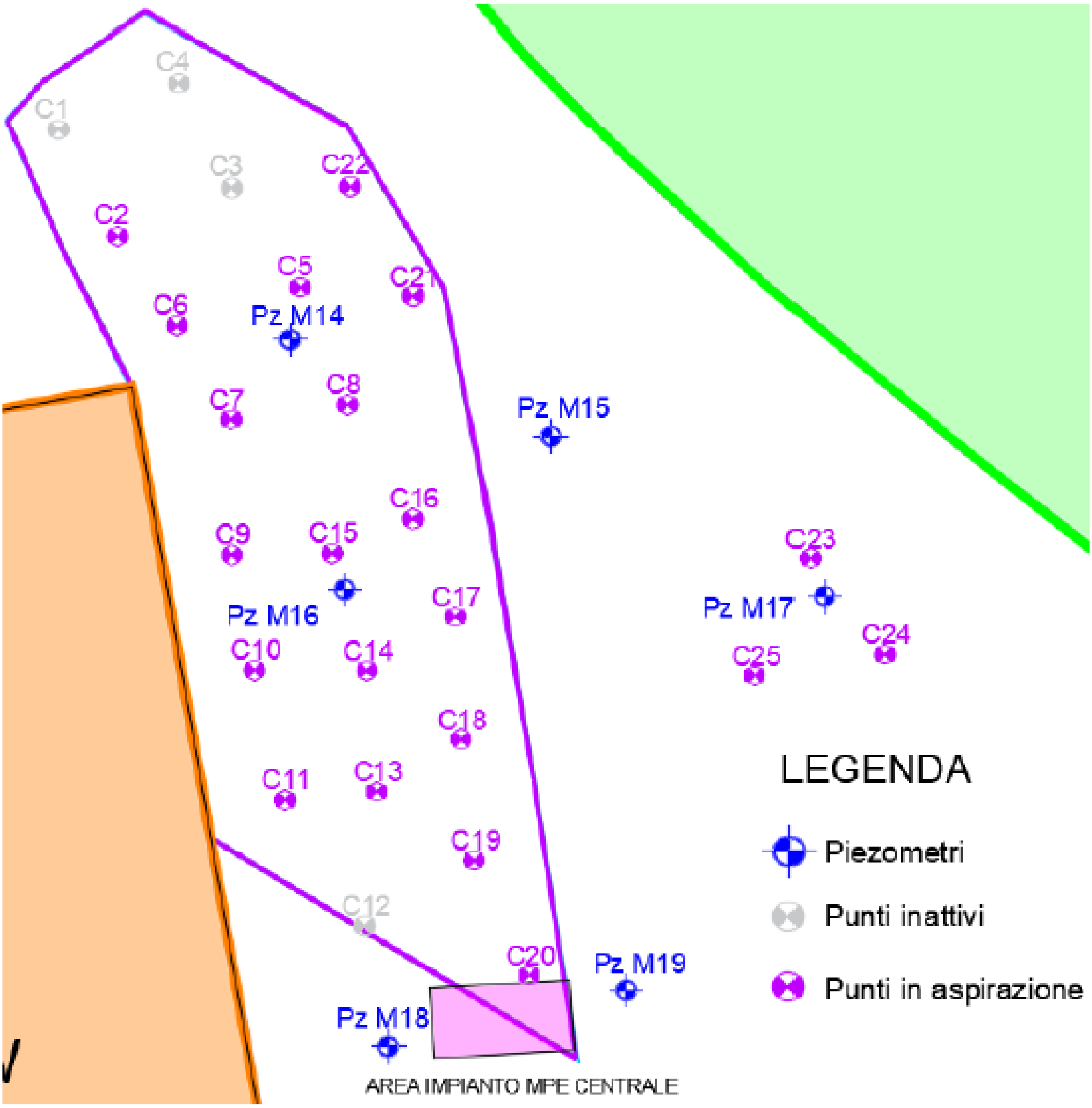
- Vacuum generated at the wellhead and induced at the control points in the different flow steps (to evaluate flow rates and operating vacuum and radius of influence)
- VOCs and percentages of O_2, CO_2, and LEL in the intake gas (to evaluate recovery of contaminants in the gas phase and size the air treatment system).
- Lab analysis of concentrations of contaminants in the inlet gas (to evaluate gas-phase contaminant recovery and to design the air treatment system).
- Extracted liquid flow rates and induced groundwater lowering (to evaluate system effectiveness in groundwater desaturating and to design the water treatment system)
- Possible presence of LNAPL/DNAPL (to size any de-oiling systems and to define the typology of full-scale plant)
- Lab analysis of concentrations of contaminants in groundwater taken from extraction wells (to size the water treatment system and evaluate recovery of dissolved contaminants).

4. Full-scale application

4.1 Full design system



The system consists of two suction units with which the gaseous phase mixed with the liquid phase is extracted from the wells installed through a high vacuum level. Twentytwo PVC extraction wells with a diameter of 4", screened between 1 and 7 m b.g.s, have been installed. Then the intervention areas have been prepared with the installation of a HDPE geomembrane to cover the non-paved areas and to avoid short circuits of air with the surface.



The extracted liquids first pass through a cyclone filter that separates any sand sucked from the MPE wells and then through a check filter to eliminate the finest sediments. Subsequently, the gaseous phase mixed with the liquid phase is appropriately separated in the multiphase separator where gases are separated from liquids by density. The gaseous phase is then sent to the activated carbon treatment section, while the aqueous

phase is sent to the water treatment plant. The DNAPL product eventually present in the aqueous phase is separated by a water/product gravity separator before the water treatment plant.
The inlet line to the cyclone filter is divided into 3 PVC lines of diameter ø 2", each equipped with a valve with pneumatic actuator. The valves are controlled directly by the PLC which allows the opening and closing cycles of each valve to be timed individually, so that they can work alternately or all at the same time.

After the pneumatic valves, the lines divide into a 4 or 5 point comb. Each point, equipped with a ball control valve, is connected by rigid HDPE piping with a diameter ø 1"1/4 to a suction well. The lines, properly labelled with the name of the suction well from which they come, are laid above ground up to the wellhead of competence and then connected, through a flexible pipe equipped with regulation valve, to an HDPE drop tube (slurper) with diameter equal to 1". The drop tube, allows the suction of fluids, water, vapors, and any LNAPL/DNAPL, throughout the contaminated section. The drop tubes are lowered inside the suction wells up to the desired depth, through a sealed well head and their depth can be easily adjusted on the basis of field surveys.

All the well heads, positioned above ground in order to facilitate connections and controls, are equipped with a vacuum gauge to control the depressions induced inside the well and a point of taking samples/measurement with portable instrumentation.

- The system provides a continuous operation (24/24 h) with fully automatic management through a controller with programmable logic.

4.2 Different areas characteristics that affect the project

The MPE plant was chosen for the site area that had the following characteristics:

- Presence of groundwater with maximum base depth of 7 meters from ground level.
- Low permeability
- Volatility of the contaminants (Benzene, MCB).

It should be noted that ISCO technology was preferred in a second area of the site, where the groundwater deepened in an interval with permeability greater than an order of magnitude between 7 and 15 m b.g.s., since the greater depth and permeability characteristics would have made ineffective the application of MPE in this area.

4.3 Radius of influence

ROI was calculated by performing a step test with increasing vacuum based mainly on the induced vacuum.
Considering a vacuum of 500 mbar in the extraction well, ROI was calculated around 5m.
However, for the sizing of the full-scale system, a distance of 7 meters between suction wells was considered as a precautionary measure, in order to obtain a good overlap of the areas of influence of each well and thus improve the effectiveness of the system.
This spacing also made it possible to constantly lowering groundwater above 3 meters, thus promoting the recovery of contamination in the gaseous phase.

4.4 Off gas Treatment

The fluids extracted from the various suction wells are initially collected in the two filters connected in series to retain the sand sucked and the finer sediments, then conveyed into the multiphase separator.
The collected sand is discharged manually and stored in big bags, to be disposed of in accordance with current regulations.

The separated gaseous phase is sucked by the vacuum pump and then sent to the activated carbon treatment section, consisting of n° 2 carbon filters of 1,0 m^3 each, connected in series.
Each of the vacuum pumps, along the outgoing line, is equipped with digital temperature sensor, digital pressure switch, analogical flow meter and sample tap. In addition, the manifold that conveys the extracted area to the activated carbon filters is equipped with digital thermometer, digital flow meter and sample tap.
Downstream and between the 2 filters there are 2 other sampling points for taking gas samples or making measurements with portable instrumentation.

4.5 Water Treatment

The fluids extracted from the various suction wells are initially collected in the two filters connected in series to retain the sand sucked and the finer sediments, then conveyed into the multiphase separator.
The collected sand is discharged manually and stored in big bags, to be disposed of in accordance with current regulations.

The aqueous phase is conveyed to an oil separator for the separation of any LNAPL/DNAPL. The water coming out from the oil separator is conveyed to an existing groundwater treatment plant through a 2" HDPE rigid pipe. The delivery line is equipped with non-return valve, regulation gate valve, analogical pressure gauge, analogical meter and sample tap.
Any product in free phase is stored in a special double-walled polyethylene tank with a capacity of 0,6 m^3, equipped with an overflow alarm to block the plant.

4.6 Control parameters

The daily monitoring plan foresees the detection of the operating data of the plant in order to verify the correct functioning and optimize the performance.
Specifically, the following measurements are carried out on a daily basis:

- Vacuum upstream of the cyclone filter, bag filter and vacuum pump.
- Flow rates of each vacuum pump and at the stack.
- Temperature at the outlet of each machine and at the stack.
- Ambient temperature inside the container.
- Reading of water meters at the exit of the plant and at the exit of each pump of relaunching multiphase separator.
- Groundwater level of the piezometers.
- PID (Portable Photo Ionizer) measure of the concentrations extracted by each machine, upstream and downstream of the filters and between the 2 active carbon filters.

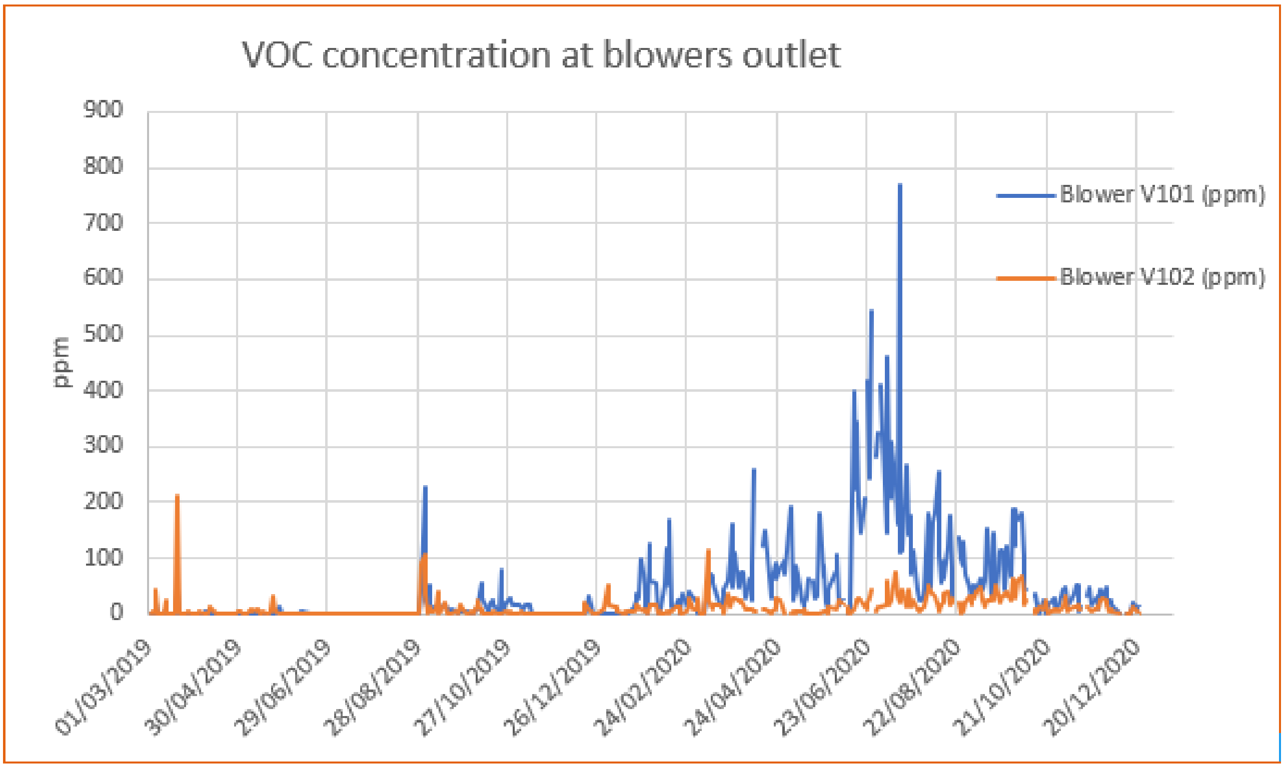
On a weekly basis, it is also detected the possible presence of sand inside the well, in correspondence of each suction point.
All the measurements above made allow in real time to assess any anomalies in the operation of the plant and to intervene in order to optimize the performance.

5. Results

5.1 Removal rate

Evaluations of the rate of contaminant extraction were carried out both through the concentrations of Volatile Organic Compounds (VOCs) detected by PID at the outlet of each vacuum pump and calculating the mass balance of the quantities of contaminants recovered in the aeriform and liquid phases.

The graph below shows the VOCs values measured during the plant's operating period.



The fluctuating trend of the graph is partly linked to variations in vacuum at the wellhead and partly to the variation in the groundwater level.
The variations in vacuum are related to clogging of the cyclone filter and/or the bag filter due to the entrainment of fine material in the extracted fluids. This results in a change in the volume extracted by the vacuum pump.
Groundwater level variations may be due to precipitation or, also, to variations in the suction rate at the wellhead.

The above trend is also repeated in the mass of contaminant recovered in the gas phase, the extraction rate of which was very significant especially in the period between March

and August 2020.
In the period after November 2020, there is a decrease in VOC concentrations indicating that contamination removal is mostly complete.
The quantities of contaminant recovered during the intervention, estimated by mass balance, are as follows:

- 53 Kg of contaminants in the gaseous phase, out of a total of 2.800.000 m^3 of air treated
- 0,64 Kg of contaminants through the pumping of the liquid phase (6.000 m^3 of water treated).

It should be noted that the rate of recovery in the gaseous phase is definitely preponderant with respect to that in the liquid dissolved phase. This situation confirms the existence of a functional desaturation induced by the system in order to promote the recovery of contamination in the gas phase.
The concentrations of contaminants detected in the control piezometers showed a decreasing trend, reaching values significantly lower than the remediation goals even after the temporary shutdown of the plant for the rebound assessment.

6. Post treatment and/or Long Term Monitoring

6.1 Post treatment and/or Long Term Monitoring

Following the shutdown of the plant, a groundwater monitoring plan was started, valid for the testing of the reclamation and consisting of 4 quarterly groundwater sampling campaigns.
The concentrations of contaminants found in the first three testing campaigns showed a decrease in concentrations with respect to the first phase of remediation respectively of 98% for benzene and 40% for MCB, without showing significant rebound phenomena and being well below the remediation goals.

7. Additional information

7.1 Lesson learnt
A fundamental aspect in the management of the plant has been the constant and frequent maintenance. In particular, the management of the plant has provided a schedule of daily interventions for: • adjusting the suction depth of the drope tubes • the cleaning of the bag filters These frequent controls have allowed to maintain a full efficiency of operation and to prevent temporary shut-down and clogging of the suction points.

Glossary of Terms

A glossary will help a you to maintain the level of precision necessary for key terms and maintain consistency across the text. We found out that sometimes terms that sounds similar like “contaminated” and “polluted” are used in the same way as synonyms in some country, while in other they have different meanings (due to legislation or for other reasons). So fill in this glossary for your key elements and of course for acronyms.

Term (alphabetical order)	**Definition**
VOC	Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature
MPE	Multi Phase Extraction
SVE	Soil Vapour Extraction
ISCO	In Situ Chemical Oxidation
CSR	Threshold risk concentrations (calculated with site-specific risk analysis)
PLC	programmable logic controller
ROI	Radius of influence
MCB	Monochlorobenzene
PID	portable photoionizer