A MULTIPHASE, MULTICOMPONENT CONTAMINATION IN A HETEROGENEOUS AQUIFER: A SIMPLE SOLUTION?

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1. INTRODUCTION

During several investigations at the location of a pharmaceutical multinational company located in the Walloon region of Belgium, different soil contaminations were discovered. As the geology of the site consists of very clayey heterogeneous sediments, the removal of the contamination is not an easy task. The local legislation, however, demands an active treatment of the soil contamination within a short timeframe.

2. SITE CHARACTERISATION AND GEOLOGY

The site is located at the lowest point of a topographical valley, nex to a small river. A residential area is situated along one of the site borders.

The geology on the site consists of alluvial deposits up to a depth of 10m; the deposits consist mainly of clayey sands with a layer of coarser (and more permeable) sand occurring at ca. 5 m depth. This small layer of more permeable sand is further on called upper shallow aquifer (USA). In the alluvial deposits several peat lenses occur. Underneath these alluvial deposits a thin layer of permeable Tertiary sands occur, which thickness varies over the site but is ca. 2m in average. Lateral groundwater flow mainly occurs in this layer, which is further on called lower shallow aquifer (LSA). The base of this permeable layer is formed by a Tertiary sandy clay, which is situated between ca. 12 and 30 m below groundwater level. Underneath this aquitard, a regional Cretaceous chalk aquifer occurs, which is used for several groundwater extractions in the neighbourhood.

Contamination occurs mainly in three different zones on the site, and consists of several pollutants. In zone I and II, chlorinated hydrocarbons are found (chloroform up to 2 g/l) as well as BTEX (up to 5 ppm) and MIBK (methhyl isobutyl ketone, concentrations up to 1.7 g/l). Pollution in the third zone consists of chlorinated hydrocarbons, mainly perchloroethylene (PCE), trichloroethylene (TCE) and daughter products. Dispersed over the site, some minor concentrations of all these contaminants occur.

As the alluvial deposits, the uppermost 10 m below ground level, are consisting of alternating sand-, clay-, and peat lenses, the groundwater movement in the upper shallow aquifer is not homogeneous horizontal, but through preferential pathways in the more permeable lenses. In general the groundwater velocities in these alluvial deposits are very slow and mainly vertical. In the Tertiary sands (LSA) however, horizontal flow occurs with an average velocity of ca. 35 m per year. This explains why in the USA the concentrations vary locally very much, while in the LSA elevated concentrations are widespread. The lateral migration risk (property boundaries) is hence situated only in the LSA, while the highest concentrations are located in the USA and keep diffusing contaminants into the LSA. In the Cretaceous aquifer, which is pumped for production use on site (ca. 300m³/h) and by neigbouring companies, some pollution is found already (ppb level). The exploitation of the chalk aquifer on site has as a consequence that it forms a hydraulic containment for al contaminants which enter the chalk, but of course it causes a strong vertical gradient through the tertiary clay, which favours the downwards movement of the contaminants.

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3. REMEDIATION CONSIDERATIONS

Several approaches for the remediation of this site have been looked at, taking into account the most important limiting factors. These are (1) potential settlements due to peat lenses in the upper shallow aquifer when pumping groundwater, (2) uncertain pumping discharge due to the heterogeneity, (3) unpredictable pathways of the contaminants, also due to the heterogeneity and (4) diffusion-controlled remediation time for contamination in the less permeable layers. An additional condition is the obligation of the local authority of cleaning-up the site within a short timeframe.

As an alternative for a sole pump&treat approach the use of the biodegradation potential of some key components, such as MIBK was looked at. In literature several examples of the biodegradability of MIBK exist. To evaluate the biodegradation capacity for this site, a biosparging pilottest was performed.

In a first step (dating ca: 3 years back), 15 underground storage tanks were excavated together with the soil surrounding them, down to the groundwater level. Before the excavation started, a sheet piling wall was installed for stabilisation purposes. The tanks were removed and the polluted soil excavated. The soil was treated in the ex-situ Soil Recycling Centre by bioremediation. The solvent recovery facility adjacent to the underground storage tanks contains above ground tanks containing solvents which are vented to the atmosphere, emitting dense explosive vapours. In consequence, this place was classified as a zone 1 area, an area which contains flammable/explosive vapours and thus only non-spark producing activities are permitted. During the excavation works, the risks of an explosion were reduced in several ways.

3.1. Biosparging pilot test

3.1.1. Concept and background

In situ air sparging is a remediation technique which has been used since more than 15 years with varying success for the remediation of volatile organic compounds dissolved in the groundwater, sorbed to the saturated zone soil particles or trapped in soil pores of the saturated zone.

In situ air and bio sparging are potentially applicable when volatile and/or easily aerobically biodegradable organic contaminants are present in saturated zones under relatively permeable conditions. The in situ sparging process can be defined as injection of compressed air at controlled pressures and volumes into water saturated soils. The primary contaminant mass removal mechanisms that occur during the operation of air/bio sparging systems include

1. in situ stripping of dissolved VOC's
2. volatilisation of trapped and adsorbed phase contamination present below the water table
3. aerobic biodegradation of dissolved and adsorbed phase contaminants resulting from delivery of oxygen.

The distinction between biosparging and airsparging is situated in the mass removal mechanism: If the main contaminant removal mechanism can be ascribed to aerobic biodegradation, the remediation technique is called “biosparging”. When the main contaminant mass removal mechanism is volatilisation in combination with stripping, the remediation technique is called “air sparging”.

3.1.2. Methodology

On site an area was selected containing intermediate contaminant concentrations during former monitoring events.

Some existing wells were used as well as 9 new wells installed for the purpose of the test. In order to minimise costs, an existing well screened between 9 and 11.5 m below groundlevel (mbgl) was used for the injection. Table 3.1 gives an overview of the wells and screen depths, Figure 3,1 shows a plan view of the test configuration.

Table 3.1 : Overview characteristics monitoring wells

Cluster	Distance from monitoring well	Monitoring number	Filterscreen (depth in m-gl)	Zone
G1	1,5 meter	G 1.0	3,5-4,5	unsaturated
		G 1.1	5,5-6,5	USA
		G 1.2	8,0-9,0	LSA
G2	5 meter	G 2.0	3,5-4,5	unsaturated
		G 2.1	5,5-6,5	USA
		G 2.2	8,0-9,0	LSA
G3	4 meter	G 3.0	3,5-4,5	unsaturated
		G 3.1	5,5-6,5	USA
		G 3.2	8,0-9,0	LSA
Existing well PZV11	1 meter	PZV 11	3,7-7,5	

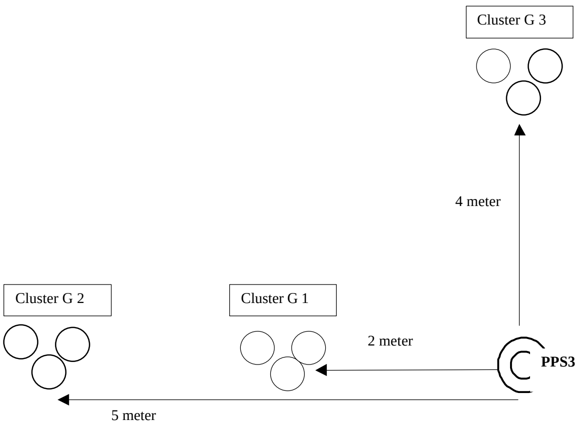

Figure 3.1: The location of the monitoring wells around the injection well in the horizontal plane.

This results in 9 monitoring wells being installed for following up the in situ sparging pilot test: 6 in the saturated zone and 3 in the unsaturated zone. In this way the biodegradation of the MIBK and chlorinated solvents in the saturated zone could be observed and at the same time the (limited) stripping and volatilisation effect of these components due to the air injection could be checked.

Before starting the air injection pilot test, a baseline monitoring was performed: the initial concentrations of the different test parameters in soil gas and groundwater from all monitoring wells and the injection well were measured before starting the injection of air.

The air injection was started on the 1st of June 2001. Air injection in the injection filter was regulated at a pressure of 1 bar (minimum possible with used equipment). The frequency of air injection was regulated at 2 hours a day (air injection during one hour, every 12h).

After a period of ca. 12 days, the frequency of air injection was decreased, since the first results of the soil gas sampling indicated a significant stripping of the chlorinated volatile compounds to the soil gas. From that time (13/6) the air injection frequency was regulated at 1 hour a day during a period of again 2 weeks. After a total injection time of about 1 month, the injection of air was stopped to evaluate the recovery of the soil and the dissolved oxygen content without further injection of air. For this purpose all monitoring wells and the injection well were analysed on the test parameters after a period of about 2 weeks (non injection period) to evaluate the recovery of the soil and the stabilisation or further biodegradation of the contaminants. The total period of time was sufficient to evaluate the possibility of biodegradation of MIBK since the theoretical half-life value for the aerobe degradation of MIBK fluctuates between 2 and 14 days (ref. Verschueren).

Monitoring

To measure the lateral extent of groundwater mounding in adjacent monitoring wells, pressure transducers (Diver, Van Essen Instruments) were used. The Divers were installed in different clusters in different vertical and horizontal zones, and the data were corrected for changes in atmospheric pressure.

Aerobic biodegradation of biodegradable compounds in the saturated zone is rate-limited by the availability of oxygen. An increase in dissolved oxygen level will enhance the rate of aerobic biodegradation in the saturated zone. An important system design parameter of in situ biosparging is therefore the increase in dissolved oxygen (DO) levels compared to the normal conditions. Typical dissolved oxygen concentrations in uncontaminated groundwater are less than 3 mg/l and in contaminated groundwater often less than 0,5 mg/l. Dissolved oxygen levels can be raised by air sparging up to 6 to 9 mg/l. At regular intervals, oxygen measurements were carried out in the groundwater of the monitoring wells.

The actual reduction in contaminant levels due to the sparging is another important design parameter. The evaluation of concentration data gives an indication of the extent of the zone of influence in terms of contaminant mass removal. It is obvious that the longer the pilot test can be run, the more reliable the gathered data are.

The aim of the pilot test is to give information about the following aspects related to in situ sparging:

- lateral movement of contamination due to air injection
- vertical movement of contamination: stripping effects and volatilisation
- biodegradation of MIBK and other solvents

3.1.3. Results

3.1.3.1. Hydraulical parameters

In the figure below a detail of recorded data during one injection event is represented.

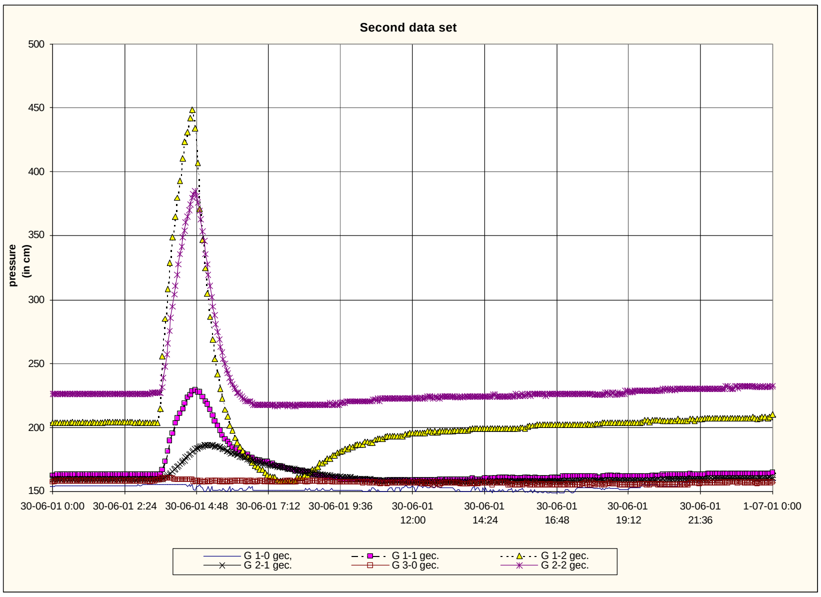

Figure 3.3: Pressure evolution in the monitoring wells during one injection event

Figure 3.3 shows the influence of air injection on the different monitoring wells in the upper shallow groundwater and the lower shallow groundwater. The effect of the air injection is the largest in the LSA (G1-2 and G2-2). This can easily be explained by the presence of the air injection filter in this lower shallow aquifer, and the higher horizontal hydraulic conductivity in this formation. The effect decreases (slightly) with the distance. The pressure is slightly lower on a distance of about 5 meter from the injection point (G2-2) compared to G1-2 (distance 2 meter).

After each injection event, a fast depletion of pressure is noticed. The measured pressure in wells G 1-2 and G 2-2 is even lower than the initial level. This is probably a consequence of the degassing of the aquifer. One can observe the fact that degassing is more intense near by the injection well (G1.2) than further away, because the amount of air in the aquifer near the injection point is of course higher.

The effect of air injection in the upper shallow aquifer is less compared to the effect in the lower shallow aquifer. This can be explained by the presence of a less permeable silt layer between the upper and the lower shallow aquifer.

Only small pressure influences are detected in unsaturated zone.

This figure shows as well the different lag times before arrival of the event for the different monitoring wells. The effect of the air injection is detected in the following time sequence: LSA, distance 2 meter > LSA, distance 5 meter > USA, distance 2 meter > upper USA, distance 5 meter

The effects of pressure measured in the different monitoring wells can only be related to the zone of air distribution if the oxygen measurements (see next paragraph) are also taken into account, since the results of the total pressure will also include the effect coming from the amount of water displaced during injection of air under pressure.

Based on the results of the divers, we can however conclude that the effect of air injection has an influence zone of more than 5 meter since G2-2 is easily influenced with a more or less similar pressure compared to the monitoring well at a distance of about 2 meter from the injection point (G1-2).

3.1.3.2. Field measurements

Figure 3.4 gives a graphical overview of the effects of dissolved oxygen levels during sparging.

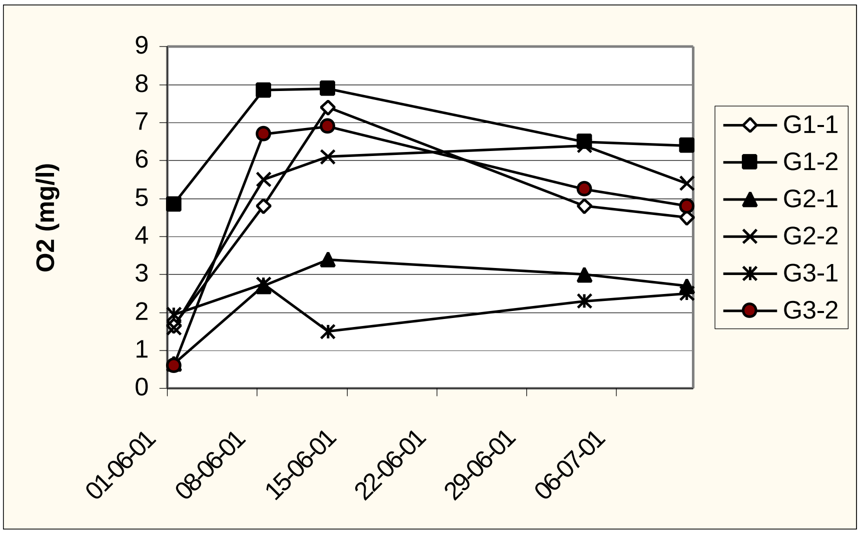

Figure 3.4: Dissolved oxygen levels (field measurements) over time

The highest dissolved oxygen levels were observed in the monitoring wells in the LSA (G1-2, G2-2 and G3-2) during the first 2 weeks. After two weeks, the frequency of air injection was decreased to a frequency of once a day, this change in frequency is also reflected in the level of dissolved oxygen, which decreased slowly to a lower steady state level.

It can be concluded that the dissolved oxygen concentrations increased roughly with the time during the pilot test and eventually reached asymptotic levels at the end of the test. The most favourable dissolved oxygen levels to stimulate biodegradation were created in the lower shallow aquifer, the presence of a less permeable layer limited the transport of oxygen to the upper shallow aquifer. Still the influence of the injection is present in the USA.

3.1.3.3. Analyses test parameters

<u>MIBK</u>

The baseline monitoring of the different monitoring well clusters and the injection well resulted in the strange conclusion that no MIBK was found in the installed new monitoring wells contrary to what was expected based on the results of monitoring wells in the neighbourhood. Increased concentrations of MIBK were however found in the injection well PSS3. The existing well PZV 11 was also used as monitoring well, since former results (2000) showed the presence of MIBK. In total, only two wells were useful for demonstrating the MIBK degradation.

Figure 3.5 shows a significant decrease in MIBK concentration in the injection well PPS3 and in PZV11. The decrease could be the result of the following mechanisms in the aquifer:

– displacement of contamination (vertical displacement by volatilisation out of pure product or by stripping, or horizontal displacement towards other monitoring wells due to movement of the groundwater)

– biodegradation

The decrease in contamination by vertical displacement of contamination can be excluded. To control the possible volatilisation or stripping effect, a headspace measurement in the injection well was performed. Direct volatilisation of the MIBK would have been easily observed, but no MIBK was found in the headspace of the injection well.

The decrease in contamination by horizontal movement of contamination due to the injection of air under pressure can also be excluded. Movement of (contaminated) groundwater due to injection of air is a known phenomenon with air sparging. In this pilot test, the horizontal displacement was followed up by the measurements of all surrounding well cluster in the lower and upper shallow aquifer in a radius of 5 meter. In none of these monitoring wells an increase in MIBK contamination was observed, although the effect of lateral movement of chlorinated solvents was clearly observed in the aquifer. This observation together with the decrease in MIBK concentration in the injection well and monitoring well PZV11 indicated that MIBK was (bio)degraded before it could reach the monitoring wells.

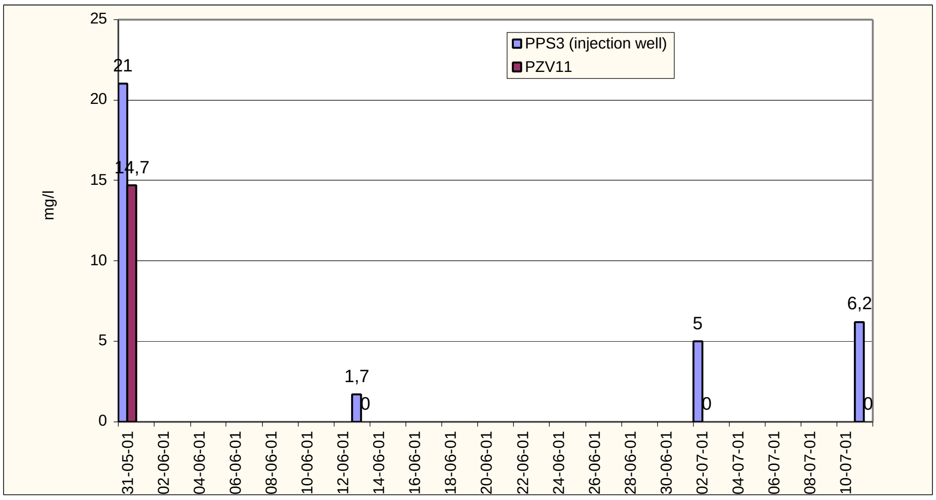

Figure 3.5: Evolution of the concentration of MIBK (mg/l) over time.

Two weeks after the stop of the air injection, all the available wells on the test site were again sampled on all test parameters. The concentration of MIBK in the injection well increased slightly. This increase in concentration can be due to the presence of a pool of MIBK in the near vicinity, resulting in a possible continuous supply of MIBK.

The supply of oxygen seems high enough to degrade these compounds since no significant consumption of oxygen is observed.

<u>Chlorinated solvents</u>

Lateral movement of groundwater

In the figure 3.6, the results of one of the non aerobic biodegradable chlorinated solvents present (tetrachloroethene (PCE)) are summarised over the time of the pilot test to describe the effect of lateral and vertical spreading of VOCs in the saturated zone due to air injection. Movement of groundwater is a known mechanism when performing in situ air sparging. If not well controlled, this movement can result in a further spreading of the plume. In a controlled way, mixing of groundwater during sparging is an important mechanism to overcome the diffusion limitations of contaminant mass transfer out of the aquifer and to overcome the diffusion limitations of oxygen transport into the aquifer. The effect of the mixing of the groundwater is the clearest for the variation in tetrachloroethene concentration. In the next paragraph (Figure 3.) it becomes also clear that tetrachloroethene is subsequently stripped into the vadose zone, where it can be removed by soil vapour extraction.

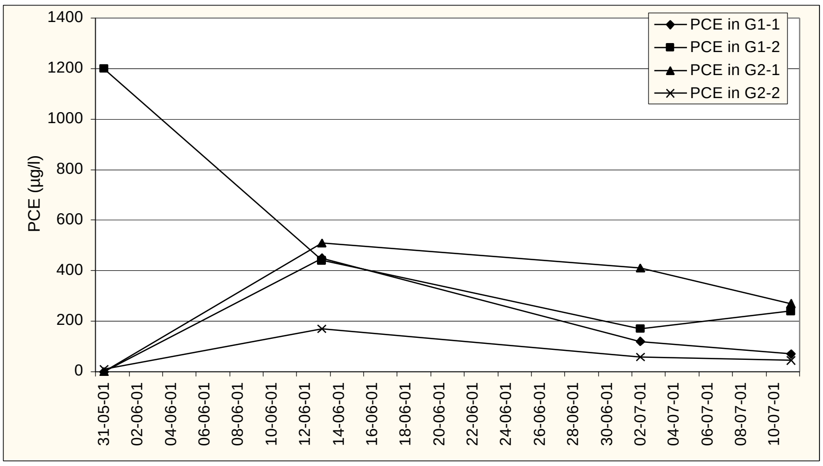

Figure 3.6: Analyses of the chlorinated solvent tetrachloroethene (PCE) in the saturated zone in two different monitoring well clusters

Vertical displacement: stripping and volatilisation

In the next figure the stripping effect of chlorinated solvents from the saturated zone to the unsaturated zone is demonstrated. The evolution of the concentrations in soil gas at one monitoring well over the time is shown, before air injection (baseline monitoring) and during air injection. The evolution of the oxygen and carbon dioxide is also represented on the same graphs.

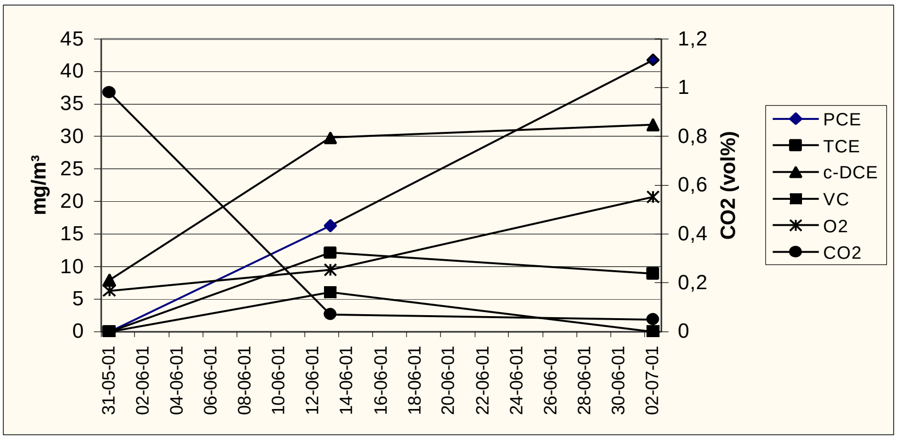

Figure 3.7: Analyses of the chlorinated solvent concentration in soil gas: stripping in the time during air sparging (monitoring well cluster G2, distance of 5 meter from the injection well)

For some dissolved contaminants, in situ air stripping is the dominant process as contaminant mass removal mechanism. The ability of a dissolved contaminant to be removed by air sparging through stripping is a function of its Henry's law constant (vapor pressure / solubility). Compounds such as trichloroethene (TCE) and PCE are considered to be very easily strippable.

In Figure 3.7 the stripping and/or volatilisation effect of the chlorinated solvents is very clear, over a time period of about one month the concentrations of these solvents in soil gas has increased significantly.

Aerobic degradation

Some VOCs are easily biodegradable under aerobic conditions (e.g. acetone, MIBK, vinylchloride (VC)..) and some of them are not (e.g. TCE and PCE).

Figure 3.7 represents the concentrations of the different VOCs as well as the oxygen and carbon dioxide levels. After an increase in VC concentration in the vadose zone, the concentration of VC decreases to detection limit at the end of the pilot test. At this point the oxygen level is increased to 20 vol %. It can be concluded that VC is degraded unther aerobic conditions in the unsaturated zone, and no stripping of VC to the outside air will occur when the oxygen supply in the vadose zone is sufficient

3.1.4. General evaluation and interpretation of the results

The pilot test results indicate that a minimum radius of influence of 5 meter can be created around an air sparging point installed about 3 to 5 meter below the groundwater level at a minimum air injection pressure of 1 bar. In this zone of influence a sufficient supply of oxygen can be obtained in the USA and LSA as well as in the unsaturated zone. This aerobic environment is favourable to stimulate the oxydation or the aerobic degradation of aerobic biodegradable compounds such as MIBK and VC. The results show a fast decrease in concentration of MIBK (saturated zone) and VC (unsaturated zone) simultaneously with an increase in oxygen level in the saturated and unsaturated zone. The relevant control measurements prove that the mass removal of MIBK is not due to lateral or vertical spreading of the contamination and can therefore only be attributed to the degradation of this compound.

The established pressure of 1 bar is favourable to remove non biodegradable compounds such as PCE and TCE by stripping and volatilisation. These mass removal mechanisms are also stimulated by the created mixing of the groundwater due to sparging. The results of the VOC compounds in the saturated and unsaturated zone show a lateral spreading in lower shallow groundwater and a vertical spreading to upper shallow groundwater and to the vadose zone (stripping and volatilisation).

3.2. Remediation plan

Based on the results of the pilot test, and taking into account the considerations as given at the beginning of chapter 3, a remediation plan for the site was designed. It consists of three main principles:

- mass removal and hydraulic containment by pump&treat in the source zones;
- active wall (by biosparging wells) for downgradient containment of the first part of the plumes;
- monitoring within the rest of the plume and at the borders of the site.

The remediation concept is visualised in Figure 3.8.

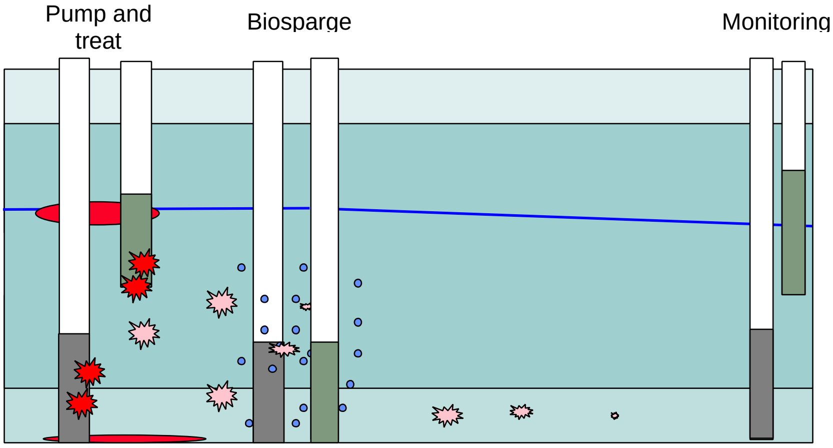

Figure 3.8: Conceptual visualisation of the remediation plan

3.2.1. Mass removal in hot-spots

In the hotspots a pump&treat mass removal system will be installed. Regarding the site geology and contamination situation, a grid of wells with spacing of approximately 10m is proposed. For the different locations on site, the maximal allowed drawdown is calculated based on local geology, occurrence of peat, and building constructions. Based on these maximal allowed drawdowns, the discharges per well in each zone are calculated. The number of wells will be between 30 and 50 divided over the three hotspot-zones, the exact number depending on the concentration data and building constructions on the site. Because of the high number of wells, mass removal will be more efficient in relation to the amount of water extracted. The consequences of some wells not having any discharge at all are minimised by the high spatial density of the wells. Well screens will be installed at approx. 10-12 m and 5-7 m below ground level, allowing very specific extraction in the most contaminated zones.

The groundwater will be treated on site using mobile treatment units.

3.2.2. Reactive zone

The reactive zone will be located just downstream the main hotspot zones. It will consist of a double array of air injection wells, with distance between the wells of approximately 10m. The air will be injected between 11 and 12 m below ground level. This will cause the aquifer to be aerobic, hence stimulating the aerobic biodegradation of MIBK. The VOC's moving downgradient will be stripped. The vapour concentrations of the VOC's in the unsaturated zone are expected to be negligible, but will be monitored throughout the operation of the reactive zone.

3.2.3. Monitoring

In the plume downgradient of the reactive zone, the concentrations of contaminants will be monitored. This will be done by sampling wells in both the upper and lower shallow aquifer, along longitudinal and transversal profiles through the plume and at the borders of the site. The results will allow a solid understanding of the natural attenuation processes going on in the pollution plume.

Meanwhile the efficiency of the remediation in the hotspot zones will be monitored by measuring groundwater concentrations in the extraction wells and in some observation wells, and soil vapour concentrations above the sparging reactive zone.

3.3. Well design

During former attempts for the clean-up of the site, an additional problem was formed by the fact that the groundwater extraction wells all blocked after some time due to very fine sediments that accumulated in the wells. In order to avoid this problem during the remediation, a test was performed. For this test 6 wells were installed, 2 in the LSA and 4 in the USA. All wells were equipped with different well casing material and filter packs (see table below).

	D1	D2	S1	S2	S3	S4
Screen depth (mbgl)	10 – 12	10 - 12	4 – 6	4 – 6	4 – 6	4 – 6
Screen material	HDPE	INOX	HDPE	INOX	INOX	HDPE (grained)
Slot size (µm)	400	200	400	100	100	40
Calibrated gravel pack (mm)	0,4 – 0,8	0,4 – 0,8	0,4 – 0,8	0,2 – 0,63	0,2 – 0,8	--

Table 3.3: Well design parameters

The geology at the test area (ca. 20m²) was first defined to be homogeneous using 4 cone penetration tests (CPT) with a vertical resolution of 2cm. One cored drilling up to 11,5 mbgl was performed using the Geoprobe© technique. The cored samples were analysed visually, and of the relevant depths samples were send to the KULeuven for grain size analysis.

In the wells pumping tests were performed at low discharge (30 – 200l/h, as predicted for the remediation) during two weeks. As with these low discharges no significant differences were observed between the different filter designs, and after two weeks no accumulation of sediments was found in the wells. Therefore it was decided to proceed with the cheapest material, being the HDPE 400 µm.

Secondly a comparison was made between the signal of the CPT and the soil samples in order to calibrate the CPT signal. The results of this investigation are used later on: before the start of the installation of the remediation wells CPT were carried out in the different zones inorder to confirm the screen depth of the extraction wells.

4. INSTALLATION OF REMEDIATION

In July 2002 the installation phase of this remediation plan was started. As in July the production on the site is at reduced intensity due to the main holiday period, the company wished for the main works to be executed during this period. During the month of July 165 wells were drilled en installed: 48 groundwater extraction wells in the USA, 48 groundwater extraction wells in the LSA, 15 clusters of two monitoring wells (USA and LSA), and 38 air injection filters (LSA). To finish the works in time, 5 different drilling teams worked at the same time and the wells were drilled using the hollow auger method, a relatively fast drilling technique. The hollow auger for the water extraction wells had an internal diameter of 200 mm and a helicoidal screw on the outside of the casing with external diameter of 320 mm. The auger was driven into the ground by a continuous rotating motion. The extraction well (HDPE casing, filter pack and bentonite seal) was installed on the inside of the hollow casing, while the auger was extracted as the works proceeded. The helicoidal screw enlarges the hole as it is withdrawn to the desired diameter while bringing the excess soil to the surface. The advantage of the system is the combination of a drilling system and the stabilization of the surrounding soil (the casing) in one single tool, which makes the technique far quicker than auger drilling using advancing casing. Consequently it made it possible to carry out the works in a very short period of time, while still ensuring the quality standards were met.

During the month of September, a second drilling phase consisting of 8 groundwater extraction wells in zone III was executed.

For the groundwater extraction wells in the LSA pneumatic pumps were used in order to avoid additional explosion risk zoning in the company. Special self-priming pneumatic pumps make it possible to pump reliably down to a predetermined level: when the water level is lowered underneath the level of the strainer, water extraction is stopped until the water level has raised again. This way no electrical water level indicators for switching the pump on and off were necessary, still taking into account the maximal allowed drawdowns as calculated for minimising the settlement risks.

The wells in the USA are pumped using two vacuum pumps (one for zone I and one for zone II). A special system (Extravac®) is installed in the wells to avoid air entering the piping when the well is pumped empty, which is a problem using classical methods.

In January 2003 the groundwater treatment units were installed. One treatment unit for zone III consists of an air stripper and an air-based activated carbon filter. The treatment unit for zones I and II consists of an influent buffer and an aerated activated carbon system (Oxycon®). In classical wastewater purification systems, activated carbon is often used in the tertiary purification phase, together with other techniques as filtration, biodegradation, etc. Activated carbon is then used to remove recalcitrant, non-biodegradable compounds from wastewater. Limiting factor is the saturation of the adsorbent (activated carbon), so that the carbon has to be replaced and/or regenerated. This result automatically is the economical question if this technique is acceptable or not. In the Oxycon® system, air is added at a pressure of 3 bar to create an oxygen saturation. The main process of treatment is hence biological, with bacteria using the activated carbon as substrate. Advantage of this system is also that more persistent components can be adsorbed on the activated carbon and have therefore more time to be degraded.

5. FIRST RESULTS

No data were available before the deadline of this paper, as the remediation is planned to start up in February 2003. During the oral presentation however the available data at the time will be presented.

6. CONCLUSION

For a contamination by several pollutants in a very heterogeneous soil, a solution based on simple principles is designed. The biodegradability of the main component was verified during a pilot test on site, resulting in the use of this characteristic for containment by means of a biosparging curtain. Following the regulatory conditions – cleanup in a short time frame – an active approach for the hot-spot zones was designed using pump & treat. The pump & treat system however is adapted to the sites limiting conditions (heterogeneity, peat), by using a high number of wells and the extraction water at low pumping rates. For the dispersed contamination at low concentrations throughout the site, the natural degradation will be followed up.

This solution was agreed by the client as it minimises interference with the production on the site, and with the regional authority as it contains an active approach of the main contaminated spots.

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