Multibarrier

Technology description:
General information & application area

Target Audience: Authorities, site owners, consultants, contractors

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1 INTRODUCTION

The multibarrier technology is an innovative in-situ technology to improve the quality of groundwater. Multibarriers consist of a combination of permeable reactive barriers (PRBs) and reactive zones (RZ), in which different pollutant removal processes are combined.

This document intends to provide general information about this technology, and its application area and boundary conditions for authorities, consultants, contractors and site owners. The document was composed within the frame of the FP7 project AQUAREHAB (GA 226565), and comprises outcomes and lessons learned during this project and the MULTIBARDEM LIFE project (LIFE06 ENV/B/000359).

2 GENERAL PRINCIPLES OF THE MULTIBARRIER TECHNOLOGY

2.1 CONCEPT

A multibarrier is a sustainable in-situ passive solution to contain and treat contaminated groundwater. It consists of a tailor-made combination of different types of permeable reactive barriers and reactive zones in which different pollutant removal processes are active. The groundwater flows through the system during which the pollutants are degraded or immobilized. As such, multibarriers prevent further spreading of the pollution to the downstream area.

Groundwater is the main source of drinking water in Europe. Contaminated groundwater is one of the major concerns for the European society in the beginning of the 21st century. Especially the Water framework Directive (and its daughter Directive on groundwater) states that the water and groundwater quality must be improved before the year 2015. Recently, *in-situ* treatment is becoming more interesting for aquifer treatment as the technology is developing and becoming more reliable and accepted.

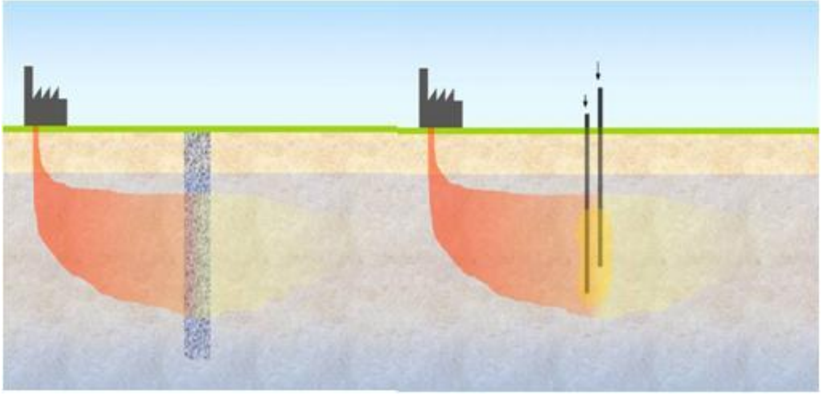

Figure 1: Schematic representation of a permeable reactive barrier (LEFT) and reactive zone (right).

A very attractive *in-situ* concept on the one hand is the "**Permeable Reactive Barrier (PRB)**", a technology in which a trench is made perpendicular to the groundwater flow. This trench is filled with a coarse material in which a pollutant removal process (biological, chemical reduction, sorption, ...) is induced to remediate the passing groundwater. On the other hand "**reactive zones (RZ)**" represent a promising in-situ remediation technology, where, locally, pollutant removal processes are induced by injection of slurries/liquids containing reactive products or degradation stimulating products (without excavation).

Mostly, PRBs and RZs are designed to abate specific pollutants. However, at many sites the polluted groundwater contains a mixture of a variety of both organic and inorganic contaminants. The abatement of pollutant mixtures may not be possible with a simple barrier/zone which is based on removal of the pollutants by either physico-chemical or biological processes. However, complex pollutant mixtures might be treated using a combination of different reactive barriers/zones. Such a combination is defined as a **Multifunctional Permeable Barrier** (MULTIBARRIER). The multibarrier approach is a tailor made technology and requests the efficient synergistic interaction and compatibility of different pollutant removal processes, often of microbial and physico-chemical key-components of the system. An example of a multibarrier is given in Figure 2.

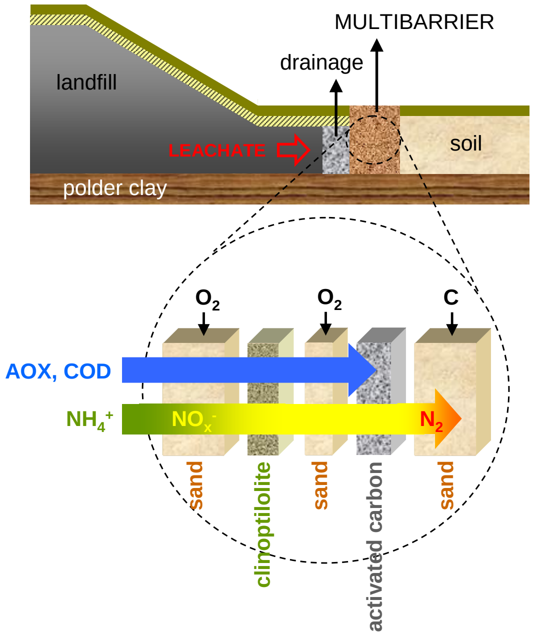

Figure 2: Example of a multibarrier system (LIFE-project MULTIBARDEM).
Multibarrier concept that was successfully designed for the semi-passive removal of ammonium, AOX, COD and toxicity from landfill leachate. The MULTIBARRIER consists of (1) a nitrifying zone, (2) a sorption zone with clinoptilolite, (3) a second nitrifying zone, (4) a zone with granular activated carbon (GAC) for the removal of AOX and COD by sorption, and (5) a denitrifying zone.

2.2 TARGETED SUBSTANCES & REACTION MECHANISMS

Table 1 provides an overview of some substances that can be targeted by the multibarrier technology along with potential emissions sources of the different substances. In principle, multibarriers can deal with all compounds that can be degraded biologically or chemically, or that can be retained by certain materials like sorbents.

The multibarrier technology is especially useful for mixtures of pollutants or for pollutants that require different steps to be degraded.

Table 1 Examples of substances that can be tackled by the MULTIBARRIER technology.

Targeted substances		Emission sources	Potential pollutant removal processes
Class	Specific substance		
CAHs (chlorinated aliphatic hydrocarbons)	Trichloroethene (TCE) Tetrachloroethene (PCE) Cis-dichloroethene (cDCE) Vinylchloride (VC) Chlorinated ethanes …	Drycleaner activities, degreasing activities, ...	• Chemical reduction via zerovalent iron (see DL4.3 part A) • Biodegradation-anaerobic (see DL4.3 part B) • Sorption ...
BTEX	Benzene, Toluene, ethylbenzene & xylenes	Petrochemical industry Petrol gas filling stations	• Biodegradation – aerobic • sorption...
Inorganics	Ammonium	Landfill leachate	• Biologically: nitrification – denitrification • Ion exchange • ….
Oxygenates	Methyl-tert-butyl ether (MTBE) Tert-butyl alcohol (TBA) ...	Petrol gas Petrochemical industry	• Biodegradation – aerobic • ...
Metals	Nickel, zinc, ..	Metal industry	• Sorption • Bioprecipitation processes • ...
...			
Mixed pollutions	Mixtures of pollutants mentioned above	Industrial sites Overlapping groundwater plumes	combination of the above mentioned processes

2.3 DEVELOPMENT STAGE OF THE TECHNOLOGY

Within technology development, the following stages can be defined:

- A technology is very emerging when it is at the research stage (not even implemented in other sectors).
- It is emerging when it is implemented in another sector and is being developed in the concerned sector (but it is no at the pilot plant trial stage yet).
- It is becoming transferable when it is at the pilot plant trial stage in the concerned sector.
- It is transferable when it is at the full scale trial stage in the concerned sector.
- It is available when it is commercially available and in use in the concerned sector.

The multibarrier technology is transferable as:

- The technology has been studies on lab scale for a variety of pollutant mixtures.
- Pilots were performed (for instance LIFE project MULTIBARDEM)
- Steps to full scales are made

As the multibarrier technology is a combination of different types of barriers and reactive zones, it is a more complex than single barriers or zones. As such, the acceptability in Europe is expected to be a bit lower than for single barriers & zones. The latter ones are well accepted in a number of countries, although in practice more conventional methods like pump&treat are still used more frequently.

3 APPLICABILITY AND BOUNDARY CONDITIONS OF THE MULTIBARRIER TECHNOLOGY

The applicability area and boundary conditions (depth of the impervious layer, depth of the phreatic aquifer, composition of the groundwater, depth of the groundwater plume, groundwater flow, porosity aquifer, hydraulic conductivity, ...) of the multibarrier technology are determined by:

- The applicability and boundary conditions of the single barriers (or reactive zones) that are comprised within the multibarrier, and
- The type of PRBs or reactive zones that needs to be combined.
- The mixed pollutants present.

For zerovalent iron barriers and biobarriers, examples of single barriers, the applicability area and boundary conditions are described in DL4.3A and DL4.3.B, respectively.

In principle, multibarriers are applicable for all compounds and locations where single barriers/zones are appropriate. However, a number of additional aspects should be taken into account when considering a multibarrier technology:

- The impact of **co-pollutants** in the groundwater on an envisioned removal process needs to evaluated and taken into account when designing multibarriers
    - Example of positive effects (to be used in multibardems):
        - Presence of Ni in groundwater when envisioning ZVI-barrier for removal of chlorinated ethenes. Cementation of Ni (as Ni^0) on ZVI increases its reactivity.

        - Co-metabolic effects in biobarriers: for instance BTEX-compounds can serve as electron donor for biological reductive dehalogenation
    - Examples of negative effects (to be avoided by adapting the multibarrier concept)
        - High metal concentration can negatively impact biobarriers and bioreactive zones.
        - Nitrate in groundwater when envisioning a ZVI-application for chlorinated ethenes. Nitrate is a competitor for electrons and reduces the reactivity of ZVI over time.
        - Preferential substrate use in biobarriers.
- **Different pollutant removal processes** within a multibarrier need to be compatible.
    - Examples of non-compatible removal processes (to be physically separated) are:
        - Aerobic and anaerobic processes
        - Aerobic biobarriers and ZVI-barriers: the zerovalent iron will corrode fast when oxygen is present.
        - Sorption barriers and biobarriers.
    - Example of removal processes that have a positive interacting effect:
        - ZVI-reactive zone and anaerobic biological processes (biodegradation, biological metal precipitation, ...).

4 PERFORMANCE OF THE MULTIBARRIER TECHNOLOGY

The **abatement rate** can be defined as the substance concentration after the technology implementation divided by the substance concentration before implementation of the technology.

The multibarrier-technology aims at an abatement rate close to 100%, which means that flux reduction rate in the multibarrier for the pollutants is almost 100%. The local regulatory limits are determining for the exact targeted abatement rates that need to be taken into account during the barrier design. Note that generally, the multibarrier does not affect the pollution concentration upstream and does not deal with the pollution that is already downstream of the barrier. The barrier does prevent spreading of the upstream pollutants to the downstream located area.

Efficiency drivers are (1) the degradation/removal rates of the different pollutants and their breakdown products, (2) the groundwater flow velocity, (3) the thickness of the barrier (flow through path) and (4) the inactivation of the multibarrier over time (permeability & reactivity).

Longevity of the multibarrier technology: In most cases, it is needed that the technology is operational for several years up to decades. Practically, there may be needs for additional investments during these long times for some multibarrier types. The longevity is depending on the barrier type:

- ZVI-barriers: 10-30 years (expected & deduced from field data)
- Bio-barriers: years
- Sorption barriers: months to years (depending on contaminant loading)
- Multibarriers: months to years

5 COST OF THE MULTIBARRIER TECHNOLOGY

Cost drivers for the multibarrier technology comprise (1) the dimensions of the barrier (depth, length and thickness), (2) the price of the filling materials, (3) the local situation on the site (accessibility, surroundings buildings, underground constructions, type of subsurface ...), and (4) the local labour costs (country dependent), and (5) the costs of the tailor made design and feasibility test.

In general, it may be assumed that site characterization, design and contingency planning costs will be higher for a multibarrier than for P&T.

Construction costs depend highly on the type of multibarrier installed (reactive barriers vs reactive zones), and may be either higher or lower than for P&T. Therefore, multibarriers can be cost-efficient compared to P&T systems, and are more likely to be so for long-running remediations. However, much depends on the long term performance of multibarriers, and potential need for replacement of reactive materials. This remains as yet a major unknown (Horckmans et al., 2009).

Operational costs of multibarriers are normally lower than those associated with traditional groundwater remediation techniques such as P&T (pump&treat). Due to its passive nature, electricity and maintenance costs should be very low. Operational costs for reactive zones may be higher than for reactive barriers due to the required addition of nutrients, oxygen or other and higher energy use (Horckmans et al., 2009).

Monitoring costs for multibarriers may be higher than for traditional systems. PRB performance has been shown to decline with time (ITRC, 2005). Due to the large heterogeneity of in situ conditions, laboratory tests and in-situ measurements will never be able to completely predict multibarrier performance in the field. Therefore, continuous monitoring of hydrological, geochemical and microbiological performance is necessary. Regulatory monitoring requirements for these novel techniques will most likely also be higher than for traditional, “proven”, methods such as P&T. This is for example the case in Flanders, where monitoring requirements for ZVI-barriers are prescribed by the Flemish Waste Agency (OVAM, 2005). The required number of monitoring wells is much higher than that usually placed for P&T installations (Horckmans et al., 2009).

6 GENERIC APPROACH TO DETERMINE APPLICABILITY OF THE MULTIBARRIER TECHNOLOGY FOR A SPECIFIC SITE OR AREA

For a successful application of the multibarrier technologies, the following stepped approach is recommended:

Step 1: Site characterisation

A site characterisation is required for checking the application and boundary conditions associated with the technology (see section 3). The site characterisation comprises:

- Identification of the type and concentration of pollution that is present

- Evaluation of groundwater chemical data including conductivity, pH, redox potential, temperature, oxygen content as well as inorganic parameters such as Ca, Fe, K, Mg, Na, Si, Cl, SO_4, NO_3, alkalinity, TOC and DOC.
- Determination of the location of the pollution (soil, groundwater, depth, ...)
- Collection of information on the geology (type of layer, permeability, ...)
- Collection of hydrological data (groundwater flow direction, groundwater flow velocity, ...)
- Evaluation of the accessibility of the site

Step 2: Selection of pollutant removal processes

For each of the present pollutants that need to be reduced in concentration, effective pollutant removal processes need to be identified. In some cases small lab scale feasibility tests can have benefits. Next, a combination of pollutant removal processes needs to be selected that can jointly cope with the present (mixed) pollution.

In first instance, a theoretical approach can be used to combine the selected pollutant removal processes in a multibarrier configuration. Here a distinction can be made between sequential multibarriers (pollutant removal processes are physically separated) and mixed multibarrier systems (pollutant removal processes combined in the same compartment).

Step 3: Feasibility test at lab scale

It is strongly advised to verify the multibarrier concept also via a lab scale feasibility test, preferably a column test. Here the multibarrier is simulated at labscale using groundwater and aquifer material from the site. Aims of the test are:

- To evaluate the performance of each multibarrier compartment
- Evaluate the impact of co-pollutants and the interaction between the different removal processes.
- Deduce degradation/removal rates and other parameters that are needed for the design of a larger scale multibarrier system.

Step 4: Design & dimensioning of pilot/full scale

PRB-barriers can be installed as continuous barriers or funnel-and-gate systems. For the latter, permeable barrier parts (gates) are altered with impermeable barrier parts (funnels) that have the function to funnel the groundwater through the gate (Figure 3). For multibarriers, the funnel & gate concept may have advantages as a multibarrier concept often allows a more easy installation and better control of a multibarrier

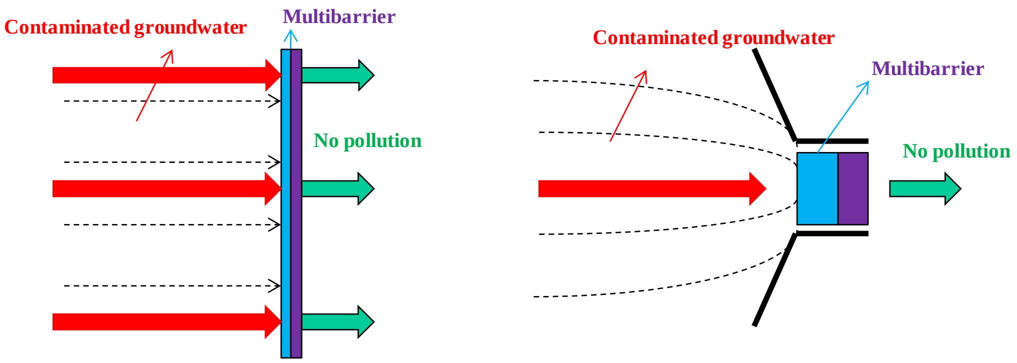

Figure 3 Schematic representation of a continuous (left) and funnel & gate (right) PRB concept.

For an envisioned installation location at the site and the selected barrier type, the required length and depth of the barrier to catch the groundwater contamination plume are determine based on the collected field information.
Next, a minimal thickness of each multibarrier compartment can be calculated based on (1) the expected pollutant concentration in the influent of the barrier, (2) the groundwater flow velocity, (3) pollutant degradation rates deduced from feasibility test result and (4) the regulatory limits. Once the dimensions are determined, the required amount of filling material can be calculated.

During the design phase, numerical modelling can be a help.

Step 5: Implementation of the multibarrier technology
This step comprises the installation of the multibarrier conform to the design parameters. Different implementation methods have been described and used.

- For reactive barriers, similar construction methods may be used as for single barriers (see DL4.3. Part A.2), such as excavation, continuous trenching and vertical hydrofracturing.
- Stability measures during excavation can consist of sheet piling, secant walls, casings or more novel techniques using biodegradable slurry. The exact method used will depend on site characteristics. Some of these stability measures (such as sheet piling or secant walls) can be quite expensive. Filling of the multibarrier system can consist of direct filling (in open excavations), prior filling in containers that are then placed into the excavation or step by step filling in different chambers.
- Construction of reactive zones is limited to the installation of the injection systems. Installation costs for reactive zones are therefore likely to be lower than for reactive barriers. Additional costs may be associated with the injected material.

Step 6: Monitoring performance & corrective actions
A post installation monitoring aims at following the performance of the multibarrier, where reduced pollutant concentrations downstream of the multibarrier are envisioned. Generally, permanent groundwater monitoring wells are installed upstream and downstream of the different multibarrier compartments and are sampled during the whole operation time. Beside chemical parameters, other parameters such as the groundwater levels before and behind the multibarrier are to be followed.

Step 7: Site closure
Generally, parts of the multibarriers are expected to remain in the subsurface once the site is closed. Multibarrier compartments which contain sorbed pollutants need to be regenerated or replaced to avoid release of the compound via desorption.

7 CONTACTS

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8 REFERENCES

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