Demonstration of the multibarrier technology for leachate containing water at the landfill Hooge Maey: 2 Pilot systems

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Two pilot-scale field demonstrations of the sequential multibarrier concepts were installed at the Hooge Maey landfill site in summer 2008 and summer 2009, respectively. In the landfill, the waste and leachate are well isolated from the environment without contaminating the groundwater. For demonstration purposes, leachate diluted with some groundwater is pumped from the landfill drainage system through the 2 multibarrier systems. The sequential multibarrier concept, based on laboratory-scale column experiments, combines microbial degradation (nitrification-denitrification) and sorption processes for the removal of adsorbable organic halogens (AOX) and chemical oxygen demand (COD). The multibarrier concept in **pilot 1** consists of the following 5 sequential compartments. AOX and COD were efficiently removed by sorption in a compartment filled with granular activated carbon, till breakthrough. The nitrification compartments, equipped with diffusive oxygen emitters, converted ammonium microbially to nitrate and nitrite, which at their turn are converted to N_2 in a downgradient denitrification compartment, supplied with an external carbon source. Ammonium was removed up to 90% and more, but the process was less efficient during winter periods. During that time, remaining ammonium concentrations were largely removed by ion-exchange in a compartment filled with clinoptilolite, until saturation of the material occurred. **Pilot 2** was intended to be an improved, simplified and cheaper version of the first pilot, and consists of 3 horizontal sequential parts, being (1) sorption part to remove AOX & COD, (2) an aerobic biological nitrification part, and (3) anoxic denitrification part. The vertical concept was found to be less efficient than the horizontal concept.

INTRODUCTION

Worldwide, many landfills were built without leachate collection systems or with faulty liner systems. Landfill leachate, generally enriched in organic matter, ammonium, and inorganic ions, can then contaminate the groundwater and pose a serious threat to the environment and human health (Ding et al., 2001; Kjeldsen et al., 2002). The extensive size of many of these leachate-contaminated groundwater plumes, covering several to hundreds of hectares (Christensen et al., 2001), renders conventional ex-situ groundwater remediation techniques economically and technically unfeasible, due to the long treatment duration and huge costs in soil excavation, groundwater pumping, and processing of the contaminated substances.
A multifunctional permeable reactive barrier (multibarrier) was recently reported by Van Nooten et al. (2008) as a semi-passive and innovative in-situ remediation technology to treat landfill leachate contamination (Figure 1). A multibarrier combines different reactive materials and contaminant removal processes, which is necessary to remove a complex pollutant mixture such as landfill leachate contamination. This paper describes the design, installation and preliminary conclusions from 2 sequential pilot multibarriers which were installed at the landfill Hooge Maey in Antwerp. At the

landfill, the main compounds of concern in the water were ammonium, COD and AOX. The tailor-made multibarrier comprised:

- biological processes for removal of ammonium (nitrification & denitrification),
- abiotic processes to reduce concentrations of AOX, COD (sorption on activated carbon), and
- abiotic removal of remaining ammonium & ion exchange on clinoptilolite).

Design and construction of multibarrier 1

MULTIBARRIER 1 is a sequential multibarrier consisting of 5 different parts in which ammonium is biologically removed via nitrification/denitrification processes, while AOC and COD are removed by sorption (figure 1). In addition a clinoptilolite buffer-system for abiotic removal of ammonium (ion exchange) was included. The multibarrier was dimensioned based on the results of the lab scale tests (Van Nooten et al., 2008) and the concept was installed in a 9 m long container which was partially installed in the subsurface (Figure 2). Via a controlling unit, groundwater was pumped through the system and oxygen and a carbon source (butyrate) were added. Multibarrier 1 was installed at the site late summer 2008. On overview of the hydraulic retention times in the different zones is given in table 1.

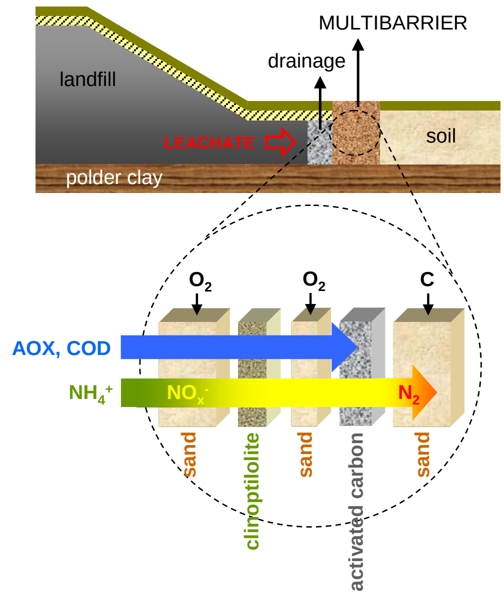

Figure 1. Schematic overview of the Multibarrier concept that was successfully designed for the semi-passive removal of ammonium, AOX, COD and toxicity from landfill leachate. MULTIBARRIER 1 consists of (1) a nitrifying zone, (2) a sorption zone with clinoptilolite, (3) a second nitrifying zone, (4)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

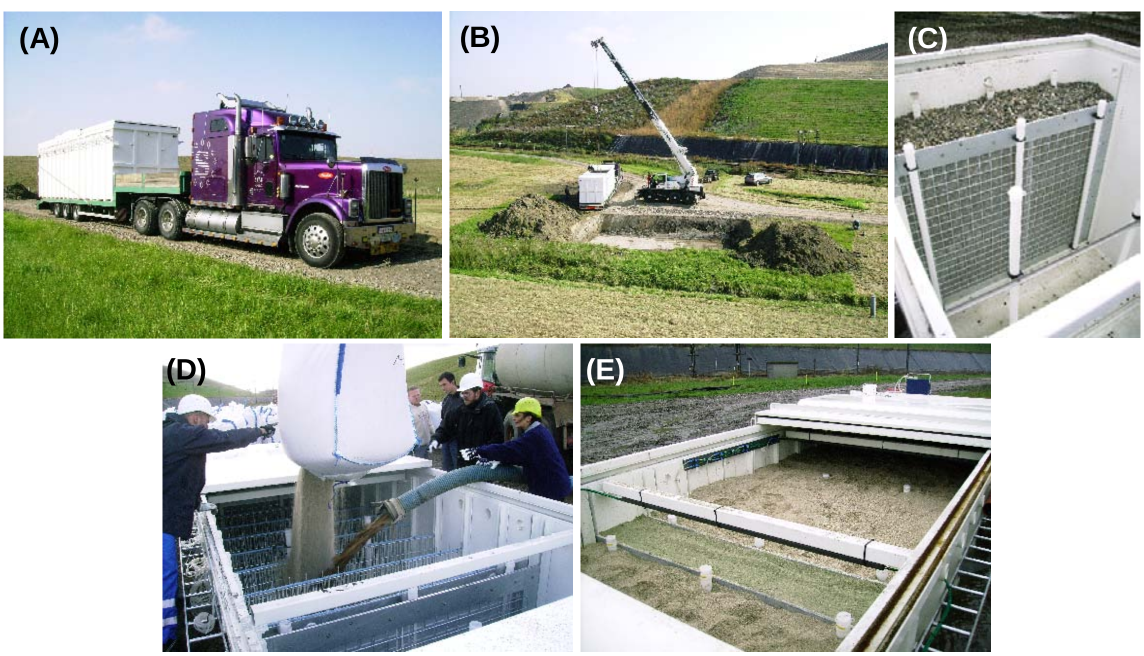

Figure 2. Photographs showing (A) transport of the container, (B) installation of the container at the Hooge Maey landfill site, partly buried in the ground, (C-D) filling of the container, and (E) the completed packing.

Table 1. Overview of the porosity, flow velocity and hydraulic retention time (HRT) for the different compartments, at a flow rate of 1-2 m³ day^{-1}.

		porosity	flow velocity (m day^{-1})	HRT (days)
1	microbial nitrification	0.39	0.6-1.2	6.6-3.3
2	sorption (clinoptilolite)	0.56	0.4-0.9	1.2-0.6
3	microbial nitrification	0.39	0.6-1.2	1.6-0.8
4	sorption (activated carbon)	0.69	0.3-0.7	1.5-0.7
5	microbial denitrification	0.39	0.6-1.2	3.3-1.6

Performance of sequential multibarrier 1

Based on the available monitoring results the following was observed:

- The diffusive oxygen delivery system is able to supply oxygen in the aerobic compartments.
- pH and electric conductivity were stable; The redox potential fluctuated clearly throughout the system;
- As the pilot system was only partially buried in the subsurface, the temperature in winter was lower than groundwater temperature (down to 2°C) and in higher in summer (up to 20°C) as shown in figure 3A. This is different from full scale systems where the temperature is about 12°C during the whole year.
- Abiotic removal of ammonium via the zeolite, was found useful to remove ammonium when the nitrification process slowed down (cold periods; temporarily toxic composition of the leachate). During the cold winter period, breakthrough of the ammonium in the zeolite, was observed. After restart of the nitrification, the clinoptilolite released ammonium, which was partially nitrified in the second nitrification compartment.
- The ammonium concentrations in the influent fluctuated between 50 and 350 mg/L and removal percentages that were obtained for multibarrier 1 varied over time (figure 3B). Due to the low temperature, initially ammonium was mainly removed abiotically by the clinoptilolite. After breakthrough only a limited amount of ammonium was removed between day 50 and day 250. Without re-inoculation, the biological activity restarted in late spring 2009 (after 250 days). Since that time the nitrification process improved (up to 80-90% removal) and remained active during winter 2010. Ammonium was stochiometrically converted to nitrate and nitrate (figure 3C), which was denitrified in the denitrification compartment (results not shown).
- COD and AOX are efficiently removed by the activated carbon to levels below the regulatory limits during the first 3-4 months of operation. Afterwards, a partial breakthrough of AOX has been observed (results not shown).
- A bromide tracer test learned that the water flow in multibarrier 1 was quite homogeneous.

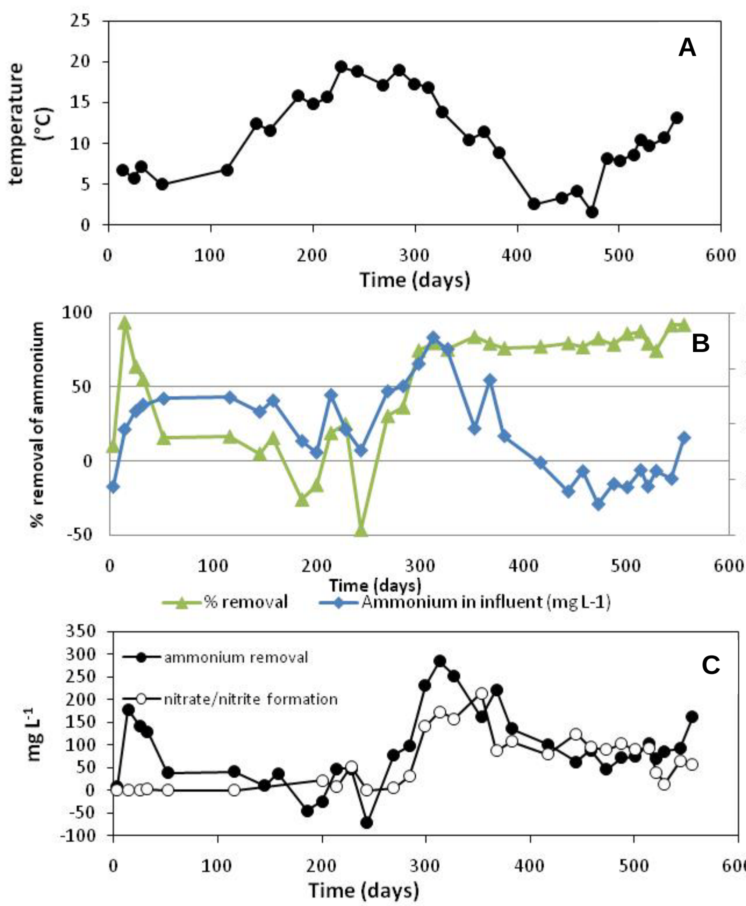

Figure 3: multibarrier 1. A. Evolution of temperature; B. Ammonium removal in the whole multibarrier; C. Ammonium removal and nitrate/nitrate formation in the first nitrification compartment.

Design and construction of sequential multibarrier 2

The second multibarrier was designed to treat the same water as multibarrier 1, and consisted of 3 sequential parts, being (1) sorption part to remove AOX & COD, (2) an aerobic biological nitrification part, and (3) anoxic denitrification part. It was intended to be an improved, simplified and cheaper version of multibarrier 1.

A vertical concept was designed, and implemented in a 4 m long column with a diameter of 1.2 m (Figure 4), which is fed at the top. In Summer 2009, Multibarrier 2 was installed next to multibarrier 1, and was fed with the same water, and controlled by the same controlling unit (Figure 5).

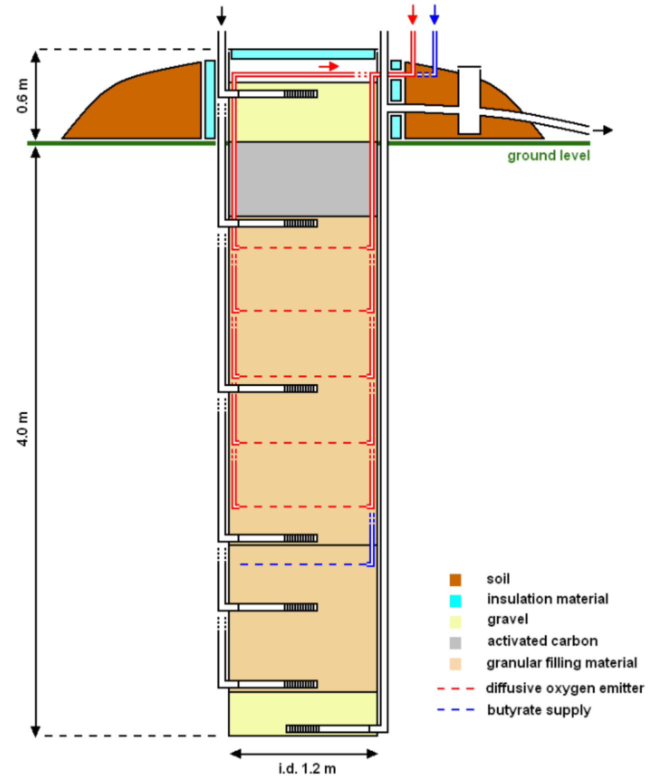

Figure 4: Schematic overview and design parameters of Multibarrier 2.

Figure 5: Installation of Multibarrier 2 at the landfill site in Antwerp.

Performance sequential multibarrier 2

As multibarrier 2 was installed in late summer 2009, less results are available. The following observation were made:

- The temperature in multibarrier 2 after filling was 20°C, after refreshment of the barrier volume groundwater temperature (12°C) was reached. In late winter values as low as 5°C were measured. In spring 2010 the values increased again to groundwater temperature. End of may 16°C was measured.
- Already 3 weeks after the start of the system, nitrification activity was observed as 56% of the ammonium was removed. Only a part of this fraction was detected as nitrate or nitrate. During the 254 days monitoring period, the ammonium removal percentage fluctuated between 10 and 97%, but were generally lower in comparison with multibarrier 1. One explanation is the low dissolved oxygen concentrations (>1-2 mg/l) that were measured in the nitrification compartment. Potentially the denitrification process started already in the anoxic zones of the nitrification compartment, which explains the relatively low nitrate and nitrate concentrations that were measured. Attempts to increase the oxygen concentration were not successful.
- A bromide tracer test and the AOC and COD measurements revealed that flow through multibarrier 1 was less homogeneous than in multibarrier 1.

CONCLUSIONS

Within the multibardem project, a tailor made multibarrier concept was designed and tested for treatment of COD, AOX and ammonium containing groundwater. In this study, the step from lab scale simulation to a pilot experiment in the field was made. The sequential multibarrier concept was found to function in the pilot system. The horizontal sequential multibarrier (multibarrier 1) showed to be a better implementation concept than the vertical sequential multibarrier (multibarrier 2). Lessons to improve the start-up and performance of the technology were learned.

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