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Aerated treatment pond technology with biofilm promoting mats for the bioremediation of benzene, MTBE and ammonium contaminated groundwater

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ARTICLE INFO

Article history:
Received 4 August 2009
Received in revised form
1 December 2009
Accepted 1 December 2009
Available online 13 January 2010

Keywords:
Groundwater remediation
Geotextiles
MTBE and benzene degradation
Compartment transfer

ABSTRACT

A novel aerated treatment pond for enhanced biodegradation of groundwater contaminants was tested under field conditions. Coconut fibre and polypropylene textiles were used to encourage the development of contaminant-degrading biofilms. Groundwater contaminants targeted for removal were benzene, methyl *tert*-butyl ether (MTBE) and ammonium. Here, we present data from the first 14 months of operation and compare contaminant removal rates, volatilization losses, and biofilm development in one pond equipped with coconut fibre to another pond with polypropylene textiles. Oxygen concentrations were constantly monitored and adjusted by automated aeration modules. A natural transition from anoxic to oxic zones was simulated to minimize the volatilization rate of volatile organic contaminants. Both ponds showed constant reductions in benzene concentrations from 20 mg/L at the inflow to about 1 μg/L at the outflow of the system. A dynamic air chamber (DAC) measurement revealed that only 1% of benzene loss was due to volatilization, and suggests that benzene loss was predominantly due to aerobic mineralization. MTBE concentration was reduced from around 4 mg/L at the inflow to 3.4–2.4 mg/L in the system effluent during the first 8 months of operation, and was further reduced to 1.2 mg/L during the subsequent 6 months of operation. Ammonium concentrations decreased only slightly from around 59 mg/L at the inflow to 56 mg/L in the outflow, indicating no significant nitrification during the first 14 months of continuous operation. Confocal laser scanning microscopy (CLSM) demonstrated that microorganisms rapidly colonized both the coconut fibre and polypropylene textiles. Microbial community structure analysis performed using denaturing gradient gel electrophoresis (DGGE) revealed little similarity between patterns from water and textile samples. Coconut textiles were shown to be more effective than polypropylene fibre textiles for promoting the recruitment and development of MTBE-degrading biofilms. Biofilms of both textiles contained high numbers of benzene metabolizing bacteria suggesting that these materials provide favourable growth conditions for benzene degrading microorganisms.

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0043-1354/$ – see front matter
doi:10.1016/j.watres.2009.12.002

1. Introduction

Fuel, fuel additives and ammonium are frequently detected water pollutants worldwide (Christensen et al., 2001; Squillace et al., 1996). Benzene, toluene, ethylbenzene, the three xylene isomers (*m*-, *o*-, and *p*-xylene, BTEX compounds) and methyl tertiary-butyl ether (MTBE) are highly soluble and therefore extremely mobile in groundwater systems (Squillace et al., 1996). Therefore, these compounds are of environmental concern and represent suitable organic contaminants for testing groundwater remediation system effectiveness. Benzene, the most toxic and water soluble BTEX compound, can be degraded by many microorganisms under oxic (Agteren et al., 1998) and even hypoxic conditions (Yerushalmi et al., 2002). MTBE biodegradation is slow and difficult due to steric effects within the molecule, but has been shown by several studies to be degraded under aerobic conditions (Ferreira et al., 2006; Schmidt et al., 2004). Notably, growth rates and biomass yields for aerobic MTBE degraders have been shown to be much lower than aerobic benzene degraders (Fortin et al., 2001). Both MTBE and benzene are highly recalcitrant under anoxic conditions (Foght, 2008; Häggblom et al., 2007). Ammonium can be aerobically oxidized to nitrate by slow growing microorganisms in a two-step process known as nitrification.

Groundwater fuel contamination is generally characterized by a large chemical oxygen demand (COD). Therefore, increased oxygen concentrations are positively correlated with biodegradation rates. However, it is a challenge to supply sufficient amounts of oxygen into contaminated aquifers due to its low solubility. Enhanced biodegradation of BTEX (Borden et al., 1997) and MTBE (Salanitro et al., 2000; Wilson et al., 2002) has been achieved by active measures such as direct oxygen injection, or passive measures like introduction of oxygen-releasing compounds into the system. However, the long-term efficiency of reactive barriers may be impacted by biofilm clogging or precipitate formation (Scherer et al., 2000).

Aerobic ponds have found worldwide application in municipal wastewater treatment; however, degradation of fuel related contaminants in combination with ammonium is poorly investigated in these systems (Thorneby et al., 2006). Photosynthetic algae and bacteria as well physical aeration are often used to support oxic degradation processes. Retaining biomass in the system is a prerequisite for efficient oxidation of contaminants and has been shown to enhance biodegradation potential in benchtop scale experiments (Korkut et al., 2006). Direct implementation of aerated trenches in contaminated shallow aquifers could represent a cost effective treatment technique, and has not yet been described to our knowledge.

The aim of this study was to evaluate the effectiveness of aerated trench systems for the reduction of BTEX and MTBE at a field scale. Our model system simulates a scenario where contaminated groundwater is passed through a treatment facility at a constant recharge rate, directly from the aquifer, before being released into the environment. The treatment aims to reduce COD and contaminant levels in the effluent by promoting aerobic biodegradation carried out by organisms contained in contaminant-degrading biofilms. We test the effectiveness of two different geotextiles, a polypropylene fleece and a natural coconut fibre. Polypropylene fibres are relatively inert with regard to extreme pH, salinity and temperature conditions in comparison to polyester (Mathur et al., 1994) and have been shown to support biofilm formation of nitrifying bacteria (Korkut et al., 2006; McLean et al., 2000; Takamizawa et al., 1993), whereas coconut textile is natural and cost efficient. Here, the implementation of two aerated trench systems after fourteen months of continuous operation is discussed in terms of contaminant degradation rates and performance of the different textiles in the system.

Table 1 – Composition of inflowing and outflowing groundwater from both basins. Values represent averages from 14 months of operation with standard deviations (±SD) for 33–40 measurements.

Parameter [mg/L]	Inflow	Outflow basin 1 coconut material	Outflow basin 2 polypropylene material
Ammonium	59 ± 5	56 ± 5	56 ± 4
Nitrate	<0.1	<0.1	<0.1
Sulphate	6 ± 4	5 ± 4	5 ± 3
Iron	5.8 ± 0.7	3 ± 2	3 ± 1
Iron(II)	6 ± 1	1 ± 1	1.7 ± 0.8
Manganese	1.6 ± 0.1	1.4 ± 0.3	1.4 ± 0.2
Magnesia	60 ± 2	60 ± 2	60 ± 2
Sodium	139 ± 7	138 ± 7	139 ± 6
Chloride	119 ± 7	120 ± 7	121 ± 6
Phosphate	1.4 ± 0.7	0.7 ± 0.3	0.5 ± 0.2
Phosphorus	0.9 ± 0.1	0.5 ± 0.2	0.5 ± 0.2
Calcium	210 ± 10	195 ± 17	197 ± 13
Potassium	13.6 ± 0.6	13.7 ± 0.6	13.7 ± 0.6
Benzene	20 ± 2	0.002 ± 0.001	0.001 ± 0.001
MTBE	3.9 ± 0.5	2.5 ± 0.8	2.5 ± 0.6

2. Materials and methods

2.1. Site location and groundwater composition

The model treatment facility was set up next to a refinery plant in Leuna, Germany. Due to spills, improper handling, and war damage, the groundwater in this area is heavily contaminated with high concentrations of ammonium, the fuel additive MTBE, benzene, and considerable amounts of iron (Table 1). Groundwater for processing was obtained from a well located downstream from the refinery.

2.2. Setup of the aerobic pond system

The system consists of two parallel basins (basin 1 and basin 2), each 5 m long, 1.15 m wide and 2.2 m deep (Fig. 1). The inflow and effluent groundwaters pass through a gravel layer of high porosity before entering or leaving the basin, simulating infiltration and exfiltration into or out of an engineered open surface water body. The groundwater flow is regulated via tubes located at the in and outflow of the basins at a depth of 2.15 m. Each system is separated into different compartments, two permeable segments of 45 cm at the sides of the inflow and outflow, filled with coarse gravel (8–16 mm) and an open water surface area of 4.1 m in length. Five barriers of geotextiles direct