



# Treatment of water contaminated by volatile organic compounds in hydroponic root mats



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## ABSTRACT

Hydroponic root mats (HRMs) are relatively new ecological water treatment technology with the aquatic vegetation forming buoyant root mats by their dense interwoven roots and rhizomes, either floating or sitting on the bottom of the water body. The aim of this study was to investigate the treatment of water contaminated by volatile organic compounds (VOCs) in HRMs under pilot-scale conditions. Floating hydroponic root mats (FHRM) and a hydroponic root mat filter (HRMF) mesocosms were established near a former industrial area in Leuna. The mesocosms received the contaminated groundwater with the main VOCs were benzene and methyl *tert*-butyl ether (MTBE). The results revealed that both systems exhibited a similar removal performance of MTBE during the two years operation. Seasonal variation was observed for benzene removal in both systems, with almost complete removal of benzene during summer period. The FHRM system exhibited higher benzene removal efficiency than the HRMF system, especially during the second year of operation. MTBE is more difficult to be removed than benzene in both systems, with overall MTBE mean removal efficiency of 32% as compare to 61% for benzene removal. Both benzene and MTBE removals are shown to be positively correlated with water loss in both systems, while air temperature only had significant influence on VOCs removal in the HRMF system. The emission rates of benzene and MTBE in the FHRM system are 8.4 and 6.9 mg m<sup>-2</sup> d<sup>-1</sup>, respectively. This removal accounted for 3.0% and 30.8% of the total benzene and MTBE removal. The emission rates of benzene and MTBE in the HRMF system were 6.0 and 1.4 mg m<sup>-2</sup> d<sup>-1</sup>, respectively, accounting for 2.3% and 8.3% of total removal of benzene and MTBE. In conclusion, HRMs can be an efficient approach to treat water contaminated by benzene in summer time, and the volatilization of benzene will decrease in the HRMs with the development of the root mat.

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## 1. Introduction

A new variant of constructed wetlands (CWs) has been developed that employs emergent water plants, similar to those used in surface and subsurface flow CWs, growing as a floating root mat on the water surface or touching to the bottom of the water body where the root mat can function as a filter for the contaminated water. In general, this system called floating hydroponic root mats (FHRMs) (Chen et al., 2016), or floating treatment wetland (Headley and Tanner, 2012), in which the mats of helophytes are floating on

the water surface. It can be called as hydroponic root mat filters (HRMFs) when the root mat touches to the rooting-proof bottom of the water body and the water is forced to flow directly through the root mat filter (Chen et al., 2016). The FHRM forms a dense floating mat of roots and rhizomes, whereby a preferential hydraulic flow of the water zone between the root mat and the non-rooted bottom can be expected. A diagrammatic lay-out of FHRM and HRMF are shown in Fig. 1. Because of their specific structure, FHRMs combines benefits of ponds and CWs, and, therefore they are used for different types of wastewater such as eutrophicated lakes and rivers (Hoeger, 1988; Li et al., 2009, 2007; Nakamura et al., 1995; Song et al., 2009; Wu et al., 2006), mine drainage (Smith and Kalin, 2000), stormwater (Kerr-Upal et al., 2000; Revitt et al., 1997; Tanner and Headley, 2008), poultry processing wastewater (Todd et al., 2003), piggery effluent (Hubbard et al., 2004) or domestic wastewater (Ayaz and

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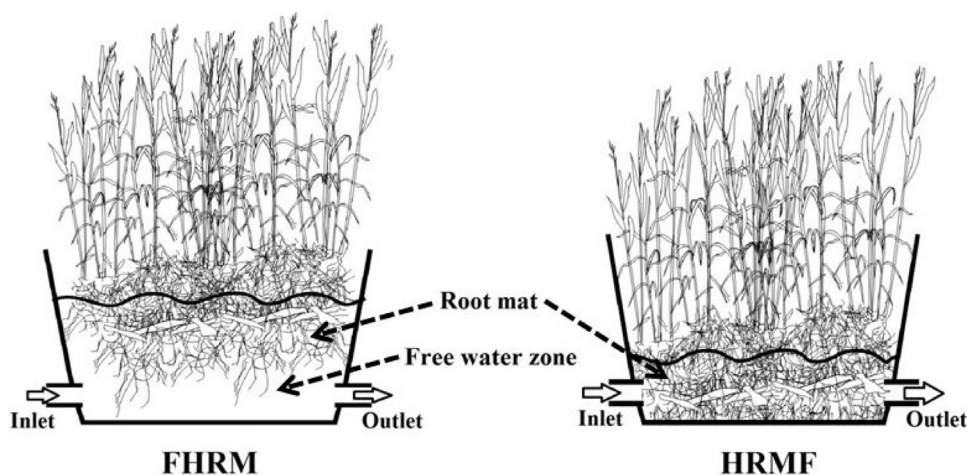


Fig. 1. Schematic lay-out of FHRM (floating hydroponic root mat) and HRMF (hydroponic root mat filter) systems.

Saygin, 1996; Cubillos et al., 2011; Hijosa-Valsero et al., 2010; Van de Moortel et al., 2010, 2011).

Recently, FHRM and HRMF have been used to treat groundwater contaminated by chemical industry. The results showed that FHRM provided better treatment performance than unplanted horizontal subsurface flow (HSSF) CW and similar like planted HSSF CW for the removal of benzene, methyl *tert*-butyl ether (MTBE) (Chen et al., 2012), and better treatment performance for low chlorinated benzenes than in planted HSSF CW (Chen et al., 2015). When treating water contaminated by perchloroethene, carcinogenic metabolite vinyl chloride was not detected in the HRMF system but in the HSSF CW (Chen et al., 2014). It's shown that the main process for benzene removal in CW is the aerobic microbial degradation with the proof of carbon isotope fractionation (Seeger et al., 2011a). Using the balancing model, Seeger et al. (2011b) proved that the degradation in the rhizosphere and plant uptake accounted for 83% and 11% of benzene removal, respectively, in the HRMF after three years of operation.

In this present study, HRMF and FHRM systems have been investigated for the treatment of water contaminated by benzene and MTBE for two years. The objectives of this study were to: (1) compare the overall removal efficiency of benzene and MTBE between the HRMF and the FHRM systems; (2) evaluate the volatilization of benzene and MTBE between the HRMF and the FHRM systems with respect of the root mats maturity.

## 2. Materials and methods

### 2.1. Setup of the pilot-scale wetlands

The pilot-scale treatment plant was established nearby an industrial area in Leuna, Germany. At this site, the groundwater was contaminated with different gasoline components, the main ones being benzene and MTBE with mean concentrations of  $10.5 \pm 2.6 \text{ mg L}^{-1}$  and  $2.1 \pm 0.4 \text{ mg L}^{-1}$ , respectively, during the investigation period (year 2010 and 2011). The main inflow water composition is shown in Table 1. All the systems consisting of a basin with a dimension of  $5.0 \text{ m} \times 1.1 \text{ m} \times 0.6 \text{ m}$ , and planted with the root mats of common reed (*Phragmites australis*). The HRMF system was started in April 2008 with the water level of 15 cm, and increased to 30 cm in September 2009, with the root mat reaching at the bottom of the basin. The FHRM system was established by the roots and rhizomes of *P. australis* in March 2010, the water level was set at 15 cm. The mean density in the HRMF and the FHRM systems were 83 and 450 shoots per  $\text{m}^2$ , respectively. The respective shoot heights were 1.7 m and 1.1 m, respectively, measured on 9th

Table 1  
Main inflow water composition during the investigation period.

Compounds	Unit	Average concentration $\pm$ standard deviation
Benzene	$\text{mg L}^{-1}$	$10.5 \pm 2.6$
MTBE	$\text{mg L}^{-1}$	$2.1 \pm 0.4$
TOC	$\text{mg L}^{-1}$	$40 \pm 7$
COD	$\text{mg L}^{-1}$	$106 \pm 12$
BOD <sub>5</sub>	$\text{mg L}^{-1}$	$59 \pm 6$
NO <sub>3</sub> <sup>-</sup>	$\text{mg L}^{-1}$	$5.3 \pm 2.9$
NO <sub>2</sub> <sup>-</sup>	$\text{mg L}^{-1}$	<0.01
Cl <sup>-</sup>	$\text{mg L}^{-1}$	$105 \pm 17$
SO <sub>4</sub> <sup>2-</sup>	$\text{mg L}^{-1}$	$22.4 \pm 25.3$
PO <sub>4</sub> <sup>3-</sup>	$\text{mg L}^{-1}$	$1.3 \pm 0.7$
NH <sub>4</sub> <sup>+</sup>	$\text{mg L}^{-1}$	$42.7 \pm 3.2$
Fe <sup>2+</sup>	$\text{mg L}^{-1}$	$5.7 \pm 1.2$
Ca	$\text{mg L}^{-1}$	$220 \pm 21$
K	$\text{mg L}^{-1}$	$11.8 \pm 0.9$
Na	$\text{mg L}^{-1}$	$120 \pm 11$
Mg	$\text{mg L}^{-1}$	$55 \pm 3$
Mn	$\text{mg L}^{-1}$	$1.6 \pm 0.1$
pH		6.8–7.7

August, 2010. Both systems were fed with the same inflow water and same inflow rate of  $6.0 \text{ L h}^{-1}$ . Both the inflow and outflow were measured using flow meters. Weather data such as precipitation and air temperature were collected every day.

### 2.2. Water sampling and analyze

Water samples at different distances (1, 2.5 and 4 m) from the inlet and at different depths (15 and 30 cm in the HRMF, 15 cm in the FHRM) as well as the inflow and outflow water samples were taken at both systems. The temperature and redox potential were measured on-site using a flow-through cell equipped with redox electrodes (Pt/Ag+ /AgCl/Cl-type Sentix ORP, WTW, Germany). For measuring the organic contaminants, 5 mL of water sample was transferred into 20 mL headspace vials, at the same time added 50  $\mu\text{L}$  bromobenzene-*d*<sub>5</sub> (with a final concentration of  $250 \mu\text{g L}^{-1}$ ) as an internal standard and 5 mL solution of NaN<sub>3</sub> (with a final concentration of  $0.65 \text{ g L}^{-1}$ ) in order to inhibit microbial activity. The samples for the organic analysis were transported to the laboratory using ice bags and stored in a cooling storage room under  $4^\circ\text{C}$  before analysis. The VOCs were analyzed by means of a headspace GC-FID (Agilent 6890 Gas Chromatograph) with a capillary column ( $30 \text{ m} \times 0.45 \text{ mm} \times 2.55 \mu\text{m}$ , Agilent DB-MTBE). The following temperature program was performed:  $35^\circ\text{C}$  (6 min),  $4^\circ\text{C}/\text{min}$  to  $120^\circ\text{C}$ ,  $20^\circ\text{C}/\text{min}$  to  $280^\circ\text{C}$  (5 min), nitrogen gas was used as the carrier

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