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Improving the treatment efficiency of constructed wetlands with zeolite-containing filter sands

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ABSTRACT

In this study the physical and chemical properties of three different lava sands used in constructed wetlands for municipal wastewater treatment were investigated. The aim was to identify those properties and mechanisms that render lava sands as highly efficient filter media which could substitute conventional, fluviatile sands. It was shown that although lava sands per se may be suitable filter materials, the presence of zeolite minerals within the lava sands enhances the purification efficiency tremendously. Zeolites not only increase the sorption capacity, but even more important, they are able to absorb water in large amounts, which in turn leads to stronger swelling. The latter reduces hydrological conductivity considerably, resulting in a longer contact time to eliminate pollutants. A simple mineralogical survey of filter materials for the presence of zeolites may render many installations of constructed wetlands successful.

1. Introduction

Freshwater resources on earth are diminishing rapidly and human activities continue to affect the quality and quantity of these resources detrimentally. As such, there is urgent need for suitable methods of wastewater renovation. Constructed wetlands have been used successfully for municipal, industrial and landfill leachate treatment in cold as well as warm climates. They have a great potential for widespread use due to their low operational costs and little need for technical expertise of operational staff. Facilities have been successfully applied in industrialized as well as in emerging countries, e.g., Portugal (Albuquerque et al., 2009), Taiwan (Lin et al., 2008), Japan (Ong et al., 2010), India (Kadam et al., 2008), Nepal (Laber et al., 1999; Shrestha et al., 2001; Singh et al., 2009), China (Chan et al., 2008; Chen et al., 2008), Estonia (Poldvere et al., 2009) and Turkey (Yalcuk and Ugurlu, 2009). A drawback of these systems is their relatively high demand for land, especially when a series of several wetlands is required to reach the regulatory targets of the treated wastewater (Singh et al., 2009). To reduce the demand for land highly effective filter materials with high purification efficiencies are required. Lava sands have been discussed to be promising filter materials (Alfs and Reinhardt, 1999; Drescher and Hasselbach, 2010; Drescher et al., 2007; Machate et al., 1999), which seem to overcome the limitations of the conventionally used, fluviatile sands. With a simple vertically operated setup lava sand filters are capable to purify wastewater efficiently, reaching COD (chemical oxygen demand) and ammonium removal rates that exceed 80% and 95%, respectively (Drescher and Hasselbach, 2010; Drescher et al., 2007). Lava sands are often of local weathering origin (Alfs and Reinhardt, 1999) and are hence accessible to many small communities. However, a direct comparison to commonly used fluviatile sands and a scientific investigation addressing the high purification efficiency and the suitability of different lava sands has never been done. Over the years, agencies and contractors using lava sands for the construction of vegetated soil filters gained experience about the suitability of various materials only by trial-and-error attempts. Regarding commonly used materials like gravel or fluviatile sands, research has only focused on relative differences in filter capacity between materials (Abe and Ozaki, 2007; Albuquerque et al., 2009; Drizo et al., 1999; Kietlinska and Renman, 2005; Li et al., 2008; Poldvere et al., 2009; Sakadevan and Bavor, 1998; Seo et al., 2008; Yalcuk and Ugurlu, 2009) and the influence of vegetation growing on the filters (Sikora et al., 1995). The underlying purification mechanisms remain unclear. Furthermore, many studies have been based on small *ex situ* to medium scale *mesocosm* experiments (Abe and Ozaki, 2007;

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Albuquerque et al., 2009; Chan et al., 2008; Kietlinska and Renman, 2005; Lin et al., 2008; Ong et al., 2010; Reyes et al., 1997; Sakadevan and Bavor, 1998; Seo et al., 2008; Shanableh and Kharabsheh, 1996; Sikora et al., 1995; Yalcuk and Ugurlu, 2009) and only few have investigated full-scale facilities in operation which would allow to draw conclusions about retention times, hydraulic conductivity and water flow paths (Chen et al., 2008; Kadam et al., 2008; Poldvere et al., 2009; Yalcuk and Ugurlu, 2009).

In this study lava sands and conventional, fluviatile sands were compared in terms of their purification capacity. Further, the physical, chemical and mineralogical characteristics of three different, commercially available lava sands were investigated and their purification efficiency in reed grown soil filters compared. With the results it was aimed to identify those characteristics that render lava sands more efficient than fluviatile sands in municipal wastewater purification.

2. Methods

2.1. Set-up of constructed wetland

To take advantage of the high purification rates of constructed wetlands operating with lava sands, the German "Entsorgungsverband Saar" – responsible for wastewater management in Saarland – has installed 12 municipal plants operating with lava sands in vertical flow regimes to treat wastewater of mixed sewer systems. All of these systems convince with high removal rates of COD, ammonium and phosphorous (see Table 1). The most recently installed filter at Riesweiler (Blieskastel, Saarland, Germany, 25 km southeast of Saarbrücken) was used as the research unit. This facility is connected to a mixed sewer system serving 100 residents and has been in operation since October 2007.

Table 1
Selection of nine constructed wetlands in Germany with lava sand as filter material. Listed are the removal rates of COD, NH_4 and P in %.

Municipality	PE*	Start of operation	COD	NH_4	P
Borg	450	05.01.2006	87.6	96.2	69.7
Büschdorf	310	05.04.2005	95.0	98.3	78.9
Faha	450	09.11.2006	80.0	95.8	43.4
Medelsheim	500	08.02.2007	80.3	97.3	56.7
Oberleuken	600	03.02.2006	88.3	97.5	68.8
Riesweiler	100	03.01.2008	93.2	–	77.5
Seyweiler	180	10.01.2007	82.5	99.3	46.5
Tettingen-Butzdorf	500	28.09.2006	85.3	94.7	58.3
Utweiler	70	05.01.2007	81.7	99.4	50.7

* Population equivalent.

Primary treatment of the wastewater takes place in a sedimentation pond of 300 m^3 (see Fig. 1). Two pumps charge alternating separate vegetated soil filters, from which the investigated filter is divided into F1, F2 and F3 with an area of 50 m^2 each. For drainage a layer of 25 cm of gravel was filled into the filters and covered with an 80 cm layer of three different lava sands from three different suppliers. Each filter has four inlets with attached baffles and four drain pipes that allow separate sampling of the effluent.

The sands – designated F1, F2 and F3 – have similar properties with a soil texture of 86–91% sand, 8–12% silt and <3% clay, and carbon contents of $\leqslant$0.06% C_{org} and $\leqslant$0.14% C_{inorg}. The constructed wetlands were planted with *Phragmites australis* (4 plants per m^2).

Filters are fed intermittently with one week of loading followed by one week of resting, where filters become dry and fully oxic again. Average loading reaches a maximum of 80 mm d^{-1} during dry weather conditions and 120 mm d^{-1} during rainy periods.

2.2. Analytical methods

To determine the hydraulic conditions of the constructed wetland the filters F1 and F3 were equipped with seven spatial TDR-probes (time domain reflectometry) of 80 cm length and six temperature sensors. Fig. 3 illustrates the arrangement of these probes around the baffles. The TDR-probes were installed between the baffles to asses the spatial distribution of the water flow around the wastewater inlets. The distance of the TDR-probes to the centre of the baffles in field F1 was 70, 140 and 175 cm. As preliminary results indicated a very high infiltration capacity for F3, the probes in this field were installed at 45, 70 and 95 cm. The TDR signal was measured with a TDR100 (Campell Scientific Inc., Logan, USA). With the recorded signals it was possible to measure the mean water content of the sands as well as the water content profile along the TDR rods and around the baffles. For a more detailed description of the TDR system and its trace analysis see (Bänninger et al., 2008).

Changes in hydraulic conductivity due to swelling of the wet lava sands were determined in the laboratory using plastic tubes (i.d. 6 cm, height 58 cm) capped with a fine-meshed grid at the bottom end and filled with lava sand to a depth of 20 cm. The tubes were filled with water and based on the time the water needed to percolate through the sand-filled columns the hydraulic

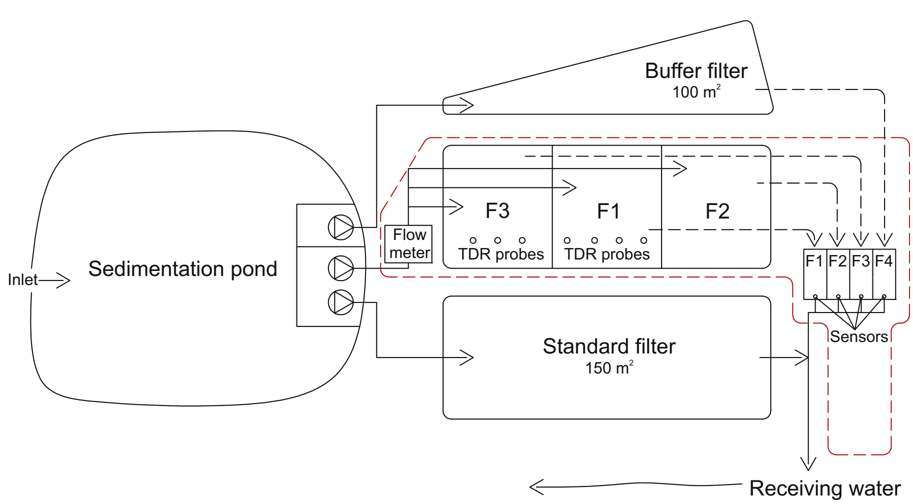

Fig. 1. Schematic setup of constructed wetland at Riesweiler with the lava sand filters F1, F2 and F3.