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Use of blast furnace granulated slag as a substrate in vertical flow reed beds: Field application

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Abstract

Research was conducted at Middle East Technical University (METU), Ankara, Turkey in 2000 to determine whether a reed bed filled with an economical Turkish fill media that has high phosphorus (P) sorption capacity, could be implemented and operated successfully under field conditions. In batch-scale P-sorption experiments, the P-sorption capacity of the blast furnace granulated slag (BFGS) of KARDEMİR Iron and Steel Ltd., Co., Turkey, was found to be higher compared to other candidate filter materials due to its higher Ca content and porous structure. In this regard, a vertical subsurface flow constructed wetland (CW) (30 m^2), planted with *Phragmites australis* was implemented at METU to treat primarily treated domestic wastewater, at a hydraulic rate of 100 mm d^{-1}, intermittently. The layers of the filtration media constituted of sand, BFGS, and gravel. According to the first year monitoring study, average influent and effluent total phosphorus (TP) concentrations were 6.61 ± 1.78 mg L^{-1} and 3.18 ± 1.82 mg L^{-1}; respectively. After 12 months, slag samples were taken from the reed bed and P-extraction experiments were performed to elucidate the dominant P-retention mechanisms. Main pools for P-retention were the loosely-bounded and Ca-bounded P due to the material's basic conditions (average pH > 7.7) and higher Ca content. This study indicated the potential use of the slag reed bed with higher P-removal capacity for secondary and tertiary treatment under the field conditions. However, the P-sorption isotherms obtained under the laboratory conditions could not be used favorably to determine the longevity of the reed bed in terms of P-retention.

Keywords: Vertical subsurface flow reed bed; Phosphorus treatment; Blast furnace granulated slag (BFGS); Turkey

1. Introduction

Excessive phosphorus (P) loading that is contributed by urban runoff, agricultural runoff, erosion from agricultural land and wastewater effluents can disturb the natural balance of the aquatic ecosystem (Brooks et al., 2000) and thus trigger eutrophication of waterbodies (Hillbricht-Ilkowska et al., 1995). In order to prevent the entrance of P-species into receiving waterbodies, recent studies have focused on alternative P-removal technologies that are economically feasible (Brooks et al., 2000). As an ecological engineering alternative to conventional and chemical based wastewater treatment methods, the use of subsurface flow (SSF) constructed wetlands in the removal of P, has been reported in several studies over the last two decades (Reddy and Smith, 1987; Mitsch and Jørgensen, 1989; Mitsch and Cronk, 1992; Moshiri, 1993; Kadlec and Knight, 1996; Pant et al., 2001).

In SSF constructed wetlands, the main P-removal mechanisms are adsorption, complexation and precipitation,

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storage, plant uptake, and biotic assimilation (Watson et al., 1989). Even though vegetation, detritus, fauna and microorganisms are important sinks for P in the short term, substrate is the main sink for P in the long term (Sakadevan and Bavor, 1998). The abiotic adsorption of phosphorus (P) to the substrate has also been reported as the major P-removal mechanisms in constructed wetlands by several researchers (Richardson, 1985; Reddy and D'Angelo, 1994; Kadlec and Knight, 1996). Hence, to select specialized substrates with conducive physico-chemical properties to P-removal, while maintaining sufficient permeability (House et al., 1994) is of utmost importance when designing constructed wetlands (Johansson and Gustafsson, 2000). Various physico-chemical properties including pH, redox potential, dissolved ions, calcium content, amorphous and poorly crystalline Al and Fe-oxides content of these substrates influence the P-sorption phenomena onto their surfaces (Froelich, 1988; Zhu et al., 1997; Reddy et al., 1999).

Some of these specialized substrates that were used for P-removal in constructed wetlands were *sand*, *gravel*, *limestone*, *shale* (Wood and McAtamney, 1996; Drizo et al., 1999; Johansson, 1997; Mann, 1997; Zurayk et al., 1997), *LWA* (commercial light weight aggregates, Johansson, 1976; Zhu et al., 1997; Maehlum and Stalnacke, 1999), *LECA* (a reactive porous media, Zhu et al., 2002), *zeolite* (natural mineral or artificially produced alumino silicates, Sakadevan and Bavor, 1998), *pelleted clay* either alone or in combination with soils (Sakadevan and Bavor, 1998), *opaka* (a siliceous sedimentary rock, Johansson and Gustafsson, 2000), *pumice* (natural porous mineral, Njau et al., 2004), *wollastonite* (a calcium metasilicate, Brooks et al., 2000), *fly ash* (Jenssen et al., 1993; Mann and Bavor, 1993; Nur Onar et al., 1996; Brooks et al., 2000) *alum*, *dolomite* and *calcite* (Ann et al., 1999; Pant et al., 2001).

Apart from natural substrates, industrial wastes such as *blast furnace slag* (BFGS), which is a porous nonmetallic co-product produced in the iron and steel industry, has been shown to have a high P-sorption capacity as has been shown earlier in batch and column experiments (Yamada et al., 1986; Mann and Bavor, 1993; Johansson, 1999a,b; Sakadevan and Bavor, 1998; Grüneberg and Kern, 2001; Johansson and Gustafsson, 2000; Korkusuz et al., 2002; Rustige et al., 2003). Even though more detailed knowledge of the removal mechanisms involved in the sorption/release of P with the BFGS are important for practical use and for estimation of the longevity of this material with respect to P, they are not very well known (Johansson and Gustafsson, 2000). Based on this information, BFGS was considered interesting for further investigation, not only because of its potential use in constructed wetlands as substrate, but because of its potential to reduce the solid waste management problems associated with the iron and steel industries (Johansson, 1999a). Sakadevan and Bavor (1998) have also suggested further research to increase the knowledge concerning the use BFGS as a filter material in constructed wetland applications. Moreover, this has only been investigated to a limited extent. Grüneberg and Kern (2001) have pointed out the necessity of long-term studies under field conditions to evaluate the P-sorption capacity of BFGS.

The objective of this paper is therefore to further investigate the P-adsorption characteristics and behaviour of blast furnace granulated slag (BFGS) under field conditions in order to elucidate their potential suitability as a filter medium in SSF constructed wetlands treating domestic wastewater. In this regard, using standard P-solutions, batch scale P-sorption experiments were performed to determine the P-sorption capacity of the BFGS provided from the KARDEMİR Iron and Steel Ltd., Co., Karabük, Turkey, and these were compared to those found in the literature. Moreover, the first-year P-treatment performance of a vertical SSF reed bed ($30\ m^2$) implemented in Ankara, Turkey that was filled with BFGS and operated intermittently with primarily treated domestic wastewater, are presented and evaluated. After one year of operation of this constructed wetland, BFGS samples were taken from the filter media of the reed bed. These samples were fractionated for P to characterize the dominant P-sorption mechanism to assess whether laboratory P-sorption results could be used to determine the longevity of BFGS media used in the field applications.

2. Methods

2.1. Site description

A vertical SSF constructed wetland with dimensions of $4.5\ m \times 6.5\ m \times 0.60\ m$ ($W \times L \times D$) with a surface area of around $30\ m^2$ was implemented on the campus of Middle East Technical University (METU), Ankara, Turkey, in the summer of 2001. A slope of 1% was created at the bottom of the wetland to facilitate easier water collection and the bottom was sealed with a nylon sheet. The wetland was first filled with gravel (15 cm of 15/30 mm), then with sieved BFGS (30 cm of grain size <3 mm), and finally with sand (15 cm of grain size <3 mm) as the top layer. Several sizes of PVC pipes were used to distribute the wastewater flow evenly onto the reed bed. Moreover, polyethylene drainflex pipes were used to collect the treated wastewater. Constructed wetlands were planted with the shoots of the *Phragmites australis*, which were transferred from the natural reed beds on the campus and transplanted at a density of 9 seedlings m^{-2}, in May 2002. The primarily treated domestic wastewater was manually diverted from a sedimentation tank (volume $= 3\ m^3$) via spherical valves and PVC pipes to the wetlands, once a day for about an hour, yielding an influent discharge rate of $3\ m^3\ d^{-1}$ and of a hydraulic loading rate of $0.100\ m\ d^{-1}$ (Korkusuz et al., 2002). The plan-view of the vertical SSF constructed wetland implemented on the campus of METU is illustrated in Fig. 1.