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A comparison between model and experimental hydraulic performances in a pilot-scale horizontal subsurface flow constructed wetland

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ABSTRACT

A comparison between model and experimental pilot-scale horizontal subsurface flow constructed wetland (HSFCW) located in Lecce (Apulia, South Italy) has been reported in the paper. The experiments were carried out in three constructed wetlands each with a planted area equal to 15 m^2 and with water depth of 0.6 m. Tracer tests were conducted by single-shot injection of a dissolution of KBr into the inlet tubes of the beds. The objective of the study was to compare hydraulic performances in a pilot experiences and to evaluate the suitability of two-dimensional method for describing the hydraulic behaviour of the HSFCW. At the beginning of the experience and after 24 months the results show the variation of the hydraulic conductivity and a good correlation between model and physical data by modifying input parameters as a consequence of the clogging.

1. Introduction

HSFCWs are widely used for removing pollutants from wastewaters the world over. Compared to conventional wastewater treatment technologies, treatment wetlands are mechanically simple and have relatively low operation and maintenance (O&M) requirements (Nivala et al., 2012). Subsurface-flow wetlands consist of an emergent macrophyte community planted in a porous medium (usually gravel or sand), through which wastewater is passed for purification (Knowles et al., 2010).

Traditionally, the treatment based on HSFCWs separate the treatment stages. First, pre-treatment and the primary treatment are combined to eliminate solids, while subsequent stages consist of constructed wetlands and/or natural technologies (Rousseau et al., 2004; Vymazal, 2005; Cooper, 2009). While primary treatments tend to eliminate solids with septic or Imhoff tanks (Brix and Arias, 2005; Puigagut et al., 2007; Álvarez et al., 2008), HSFCWs are used for secondary and tertiary treatment (Vymazal, 2009; Ranieri et al., 2010a,b; Vera et al., 2010; Ranieri et al., 2013).

Moreover, nowadays, CWs are important as new scientific frontier application for removal from wastewater of pharmaceutical substances, particularly HSFCWs (such as paracetamol) (Matamoros and Bayona, 2006; Matamoros et al., 2007; Ranieri et al., 2011).

To date, research on flow hydraulics through the porous media of constructed wetlands has focused primarily on the assessment of relationships and interactions between microorganisms, plants and the reduction of pollutants in the system (e.g., García et al., 2005). Therefore, this study assesses and elaborates the hydraulic performance in the pilot-scale HSFCWs and observes trends over time.

Design parameters such as aspect ratio, size of the porous media and hydraulic loading rate can improve the hydraulic behaviour of constructed wetland systems by imparting a hydraulic flow behaviour that approaches that of an ideal flow system. Furthermore, the performance of constructed wetland can be enhanced by modifying such parameters (Persson et al., 1999; Garcìa et al., 2004; Alcocer et al., 2011; Zahraeifard and Zhiqiang, 2011; Gikas et al., 2013). COMSOL Multiphysics has been used to build a model that describes the hydraulic behaviour within the experimental constructed wetlands. It introduces the concept of diffusivity in porous media by comparing the transport through an artificial porous structure described in a detailed model with a simplified homogeneous porous media approach using effective transport properties.

The experiments were conducted using tracer tests (KBr), which provided the residence time distribution (RTD). Particularly, after 24 months of operating, clogging conditions in experimental HSFCW result in a lower hydraulic conductivity values.

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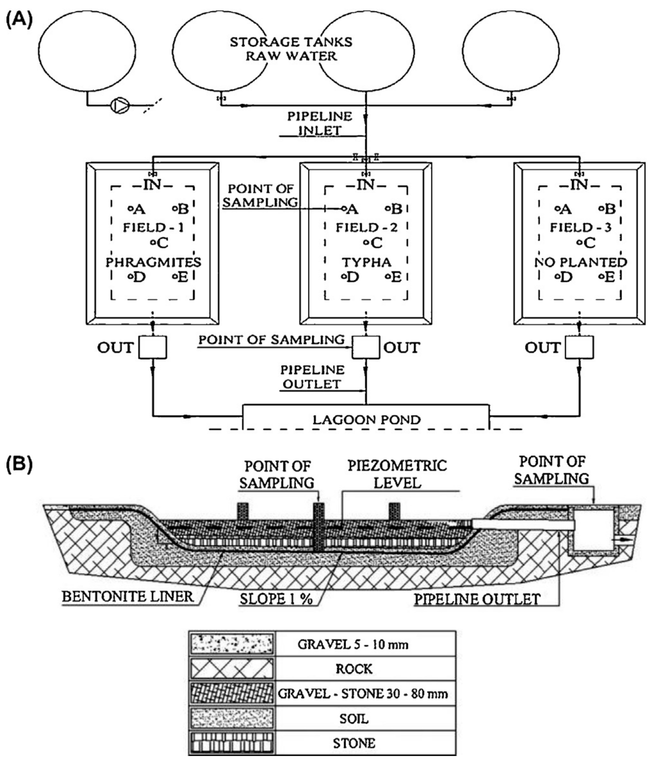

Fig. 1. Constructed wetlands pilot plant at Sternatia di Lecce, Italy: plane view (A) plan view and (B) longitudinal section.

The objectives of this study are:

- to evaluate the hydraulic behaviour of constructed wetlands not planted and planted with different species (*Phragmites australis* and *Typha latifolia*), by varying the hydraulic conditions and then evaluating the effect of clogging;
- to assess the correlation of the experimental RTD curves with the curve of the model, as a function on the variation of hydraulic characteristics and clogging.

2. Materials and methods

2.1. HSFCWs experimental plant

The experimental area includes three constructed wetland fields, two containing different species of macrophytes: *Phragmites australis* and *Typha latifolia* and the third serving as a control reactor (unplanted). Water is supplied to the fields from four high density polyethylene (HDPE) tanks; samples are obtained from eighteen sampling ports and effluent is stored in two lagoon ponds. Fig. 1 depicts the plan view of the site (Fig. 1A) and the longitudinal section of one planted constructed wetland bed (Fig. 1B). Each wetland has a planted area equal to 15 m^2 (3 m × 5 m), a water depth ranging from 0.6 m to 0.65 m and a resulting total volume of approximately 9.4 m^3. The constructed wetlands have a bottom slope of 1% to facilitate the outflow of water by gravity. The stability of the side banks is ensured by providing a 45° inclination. Five perforated tubes with 200 mm internal diameter are positioned within each field to permit collection of water samples and control of water levels. The bottom of each reactor is waterproofed with a bentonite liner that is permeable to plant roots but largely impermeable to water. The liner consists of three layers: an upper geotextile 220 g/m^2, a lower geotextile 110 g/m^2, and sodic powdered bentonite 4670 g/m^2, containing approximately 90% montmorillonite. The total weight of the geo-composite is 5000 g/m^2 and its total dry thickness is 6 mm. The hydraulic conductivity of the installed liner is $k < 10^{-11}$ m/s.

The hydraulic loading rate is the same for each fields and equal to 66 mm/d.

Full-scale CWs hydraulic conductivity measurements were carried out exclusively in situ by using a constant head permeameter for the direct measurement of hydraulic conductivity of the soil (Mastrorilli et al., 2001; Ranieri, 2003; Ranieri, 2012; Ranieri and Young, 2012).

Raw water is supplied at the reactor inlet and passes slowly through the filtration medium under the surface of the bed in a generally horizontal path until it reaches the outlet zone where it is collected and discharged to the lagoon. The filtration medium consists of three layers: 0.1 m of soil, 0.2 m of stones, and 0.30–0.35 m gravel as shown in Fig. 1B. The mineral composition of the substrate is 59% calcium carbonate, 32% silica and 9% iron oxide for the rocks and gravel. The soil is a mixture of red clay and organic matter. The unplanted bed served as a control reactor. At no time during the study was the water depth above the top of the media in any of the reactors, i.e., all flow was subsurface.

The climate at the site is Mediterranean with an average annual temperature and annual accumulated rainfall of 15.6 °C and 530 mm, respectively.

2.2. Tracer injection

The tracer used in the experimental plant was the bromide because it is highly soluble, non-degradable, relatively inexpensive and can be measured quantitatively in very low concentrations. Tracer solution was added in 10 min mixed with wastewater flow in order to reduce sinking effects related to density differences.

Composite samples of the effluent from each constructed wetland were collected in 500 mL amber glass bottles using an auto sampler.

Effluent grab samples were taken approximately every 12 h from the morning of day 3 until the evening of day 9. From the morning of day 10 to the morning of day 12 samples were taken every 24 h.

Tests finished on the fourth after a total sampling period of approximately 330 h. For a time of approximately 300 h the tracer concentration was not detected and, therefore, a period of time of 300 h was enough to obtain a complete response of the tracer injection.

Residence time distribution (RTD) curves were assessed by introducing 6 kg/m^3 solution of KBr in 10 min along the first cross section of each wetland unit as a conservative tracer.

2.3. Software COMSOL Multiphysics™

The COMSOL Multiphysics™ (version 4.0), bidimensional software that use the finite element method, was utilized to build the presented model. This model introduces the concept of effective diffusivity in porous media by comparing the transport through an artificial porous structure described in a detailed model with a simplified homogeneous porous media approach using effective transport properties.

2.3.1. Hypothesis, assumptions and simplifications

The main model assumptions and simplifications are:

- The flow through the gravel media circulates under saturated conditions and can be described using Darcy's Law. This is a common assumption used in constructed wetlands, as most of the processes occur in the saturated zone, and thus, the