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Treatment of industrial wastewater with two-stage constructed wetlands planted with *Typha latifolia* and *Phragmites australis*

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ABSTRACT

Industrial wastewater treatment comprises several processes to fulfill the discharge permits or to enable the reuse of wastewater. For tannery wastewater, constructed wetlands (CWs) may be an interesting treatment option. Two-stage series of horizontal subsurface flow CWs with *Phragmites australis* (UP series) and *Typha latifolia* (UT series) provided high removal of organics from tannery wastewater, up to 88% of biochemical oxygen demand (BOD_5) (from an inlet of 420 to 1000 mg L^{-1}) and 92% of chemical oxygen demand (COD) (from an inlet of 808 to 2449 mg L^{-1}), and of other contaminants, such as nitrogen, operating at hydraulic retention times of 2, 5 and 7 days. No significant ($P < 0.05$) differences in performance were found between both the series. Overall mass removals of up to 1294 kg COD ha^{-1} d^{-1} and 529 kg BOD_5 ha^{-1} d^{-1} were achieved for a loading ranging from 242 to 1925 kg COD ha^{-1} d^{-1} and from 126 to 900 kg BOD_5 ha^{-1} d^{-1}. Plants were resilient to the conditions imposed, however *P. australis* exceeded *T. latifolia* in terms of propagation.

1. Introduction

Tannery wastewater may cause severe environmental impacts due to the pollutant levels that are commonly present; the main problems, depending on the productive cycle, are the presence of solids, nitrogen, chromium and the high organic loading. This issue has been identified by the European Commission and is described in detail in the reference document on best available techniques for the tanning of hides and skins (EC, 2003). The need for environmental and economically feasible systems is a real demand worldwide. Emphasis is given here to tannery wastewater since the search for best available technologies to accomplish the legal discharge targets may contribute, in a certain way, to the preservation of this industry, which in Portugal is considered to be of great importance due to the historical and economic value that it represents (INETI, 2000).

Constructed wetlands (CWs) have proven, to different extents, to be an interesting option for several types of industrial wastewaters that are to be treated by biological means (Vymazal, 2008; Kadlec et al., 2000), including those that have originated from the tannery industry (Calheiros et al., 2008b, 2007; Kucuk et al., 2003; Daniels, 2001). In Portugal, CWs are among the treatment processes that have no specific regulations. Most of the CWs are applied for domestic sewage and municipal wastewater treatment and only few are used for industrial purposes (Dias et al., 2006). The diversity of CW configurations makes them versatile for implementation. The target pollutant and removal efficiencies are set so the dimensioning and the scaling of the system are adequate; caution must be paid to issues such as whether the system will operate as the sole treatment or will it be integrated in an existing plant. Mechanisms underlying the functioning of these systems may be found in the literature (Kadlec et al., 2000); the choice of substrate, plant species, basin compartmentation, liners, flow structure, and other CWs components, influence their capital cost (Kadlec et al., 2000) and may be crucial for granting of the project implementation. For tannery industry wastewater treatment, detailed research data on efficiency of CWs, performance and adequate set-up are still lacking. However, efforts have already been taken for, selecting plant species tolerant to this peculiar wastewater (Calheiros et al., 2007), selecting suitable supporting media or substrate (Calheiros et al., 2008b) and for approaching the bacterial dynamics (Aguilar et al., 2008; Calheiros et al., 2009).

In order to add knowledge to the operational conditions of CWs, the performance of two constructed wetland units (CWUs) arranged in a two-stage series, one planted with *Phragmites australis* and another planted with *Typha latifolia*, was evaluated for different hydraulic loading rates (HLRs) of tannery wastewater. At the same time, the development and propagation of these plants and their enzymatic and physiological responses were followed.

2. Methods

2.1. Constructed wetlands

The monitoring of two series (named as UT for the series planted with *Typha* and UP for the series planted with *Phragmites*)

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of horizontal subsurface flow CWs was undertaken in a site located at the wastewater treatment plant of a leather company in the North of Portugal (Fig. 1). The surface area of each bed was 1.2 m^2 (length: 1.2 m and width: 1 m), the effective depth of the substrate was 0.60 m and the average depth of the liquid in the bed was 0.55 m. The substrate used in the series was Filtralite®MR 3–8 (FMR), with particle size ranging from 3 to 8 mm (from maxit to Argilas Expandidas, SA – Portugal).

The first unit of both *T. latifolia* series (UT1) and *P. australis* series (UP1) had been in operation for 17 months receiving tannery wastewater (Calheiros et al., 2007). The plants used in UT2 and UP2, *T. latifolia* and *P. australis*, respectively, were transplanted from an industrial polluted site in Estarreja, Portugal (Oliveira et al., 2001) in a range of 10 plants m^{-2}. The systems were filled with water for three weeks prior to the application of the wastewater, and were then aligned to work in series and operated for 31 months under different hydraulic conditions and interruptions in feed. Briefly, for 2 months the first unit of each system was subjected to a HLR of 18 cm d^{-1}. By the third month the systems were not fed for 24 days due to the shutdown of the production plant and a second period of operation occurred subsequently during 23 months under a HLR of 6 cm d^{-1}. During this time the wastewater supply was stopped twice. By day 479 plants were clipped, leaving around 10 cm of aboveground plant material. A third period of operation occurred during six months under a HLR of 8 cm d^{-1}, and the systems were not fed due to the shutdown of the production plant by the second month within that period. The overall hydraulic retention time in the two-stage system series, for each HLR was 7, 2 and 5 days (in the order of application). Maintenance of the systems was done according to Calheiros et al. (2007). The systems were inspected on, at least, a weekly basis concerning the overall functioning, and a general cleaning of the pipes was usually undertaken twice a month. Major attention was paid to the inlet and outlet flows – measurements were made at the sampling times, and no relevant differences were observed.

2.2. Plant parameters

Macrophytes number and height (starting from the substrate level) were registered at least monthly. For that, each CWU was divided into four zones (Fig. 1) – A and C corresponded to the inlet and outlet zones, respectively, and B and D corresponded to the left and right sides of the CWU (inlet reference point) – and at the beginning three plants were marked in each zone. Generally, plants were visually inspected on a weekly basis for toxicity signs, such as chlorosis, necrosis and malformation.

Chlorophyll content. For chlorophyll analysis, fresh circular discs from mature leaves of plants collected at the inlet and outlet of the CWUs were cut with a 10.5 mm corer, and were extracted in *N,N'*-dimethylformamide. Chlorophyll *a* and *b* content was determined according to Wellburn (1994).

Peroxidase activity (POD) determination. POD was determined in root and leaf samples of *T. latifolia* and in root, leaf and stem samples of *P. australis*, which were collected at the inlet and outlet of the CWUs and immediately frozen in liquid nitrogen. The experimental procedure described in USEPA (1994) for plant peroxidase activity determination was followed (three replicates). One gram of fresh plant tissue was ground with a calcium chloride solution. The crude extract was added to an assay mixture and absorbance readings were taken in a spectrophotometer (Novaspec II, Visible spectrophotometer) at 510 nm.

2.3. Physico-chemical analysis

Wastewater samples were taken, in general twice each month, at the inlet and outlet of the CWUs and the following parameters were determined based on Standard Methods (APHA, 1998): pH, colour (Spectrophotometric Method), chemical oxygen demand (COD; Closed Reflux, Titrimetric Method), biochemical oxygen demand (BOD_5; 5-Day BOD Test), total suspended solids (TSS; Total Solids Dried at 103–105 °C Method), Kjeldahl nitrogen (TKN; Kjeldahl Method), nitrate nitrogen (NO_3^-—N; Nitrate Electrode Meth-

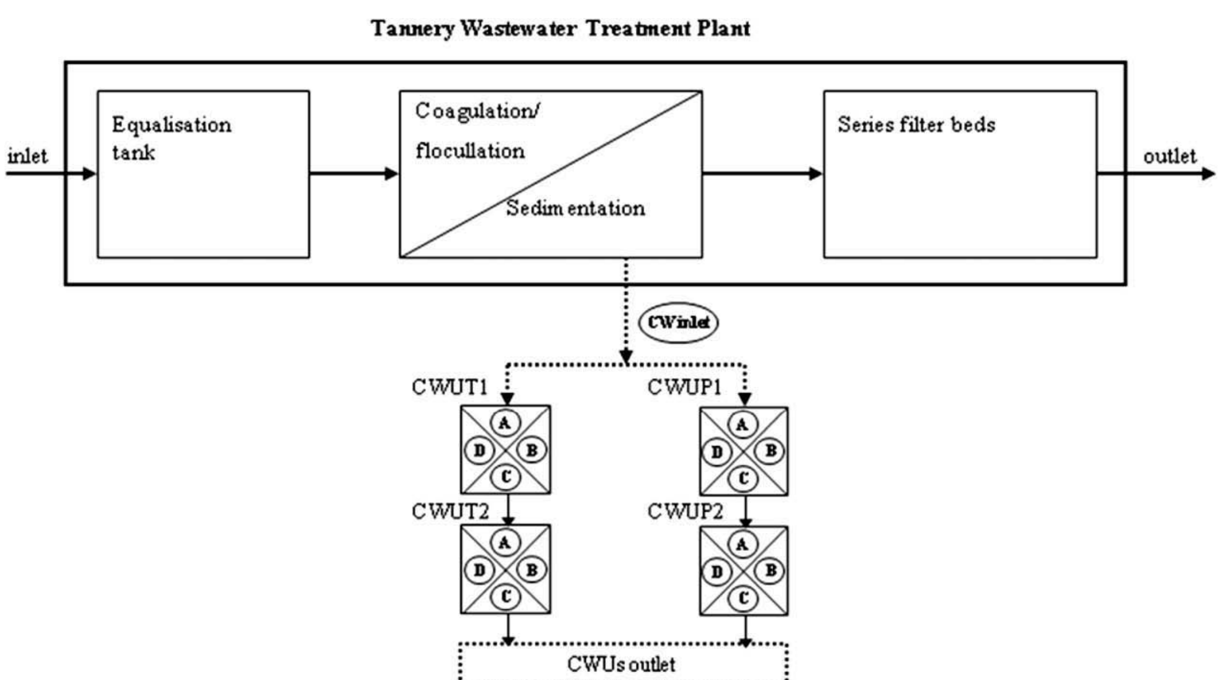

Fig. 1. Schematic representation of the constructed wetland units (CWUs) (UT1 and UT2: units with Filtralite®MR 3-8 planted with *Typha latifolia*, UP1 and UP2: units with Filtralite®MR 3-8 planted with *Phragmites australis*).