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“THE PLANT TREATMENT CHALLENGES OF WASTEWATER FROM AGRICULTURE AND INDUSTRY”

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Valorisation of wastewaters - MACROPHYTES

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Abstract

In contrast with early approaches, XXI century environmental technologies aim to be less resources consuming concerning energy and materials. Therefore, there is growing interest in the use of different macrophyte species as a simple and energy efficient method of wastewater treatment. Plants have shown the capacity to withstand relatively high concentrations of chemicals and nutrients being able to transform the compounds into less toxic metabolites. The aim of this study is to evaluate the efficiency of two emergent macrophytes naturally occurring in Portugal, *Phragmites australis* and *Iris pseudacorus*, on the treatment of urban effluent through the characterisation of wastewater before and after the treatment, at physico-chemical and ecotoxicological levels. Experiments were carried out in a greenhouse under monitored conditions. Plantations of the two species were done on a two layer bed of gravel (5 cm) and sand (25 cm) in tanks of 120 l. Results on physico-chemical parameters and ecotoxicological evaluation of the wastewater will be presented and discussed.

Key words

Wastewater treatment; macrophytes; *Phragmites australis*; *Iris pseudacorus*; ecotoxicology.

Introduction

Environmental Technologies suitable for the XXI century aim the recycling and recovery of nutrients or pollutants in contrast with the early approach of treatment technologies. The use of aquatic plants as a simple and energy efficient method for recovery of nutrients and removing contaminants from wastewaters and polluted natural waters presents an alternative technology with a high potential for application in small/medium size cities, industry and agriculture - Wetland ecosystems, including Constructed Wetland (CW). They are based on the principle of infiltration – percolation and integrate all interactions among different species of microorganisms, roots of the plants, substratum, air, sun, and water.

Aquatic plants occur in water bodies enriched by natural processes and by urban, industrial and agricultural activities. The larger aquatic plants growing in this habitat are usually called macrophytes. The term includes aquatic vascular plants (angiosperms and ferns), aquatic mosses, and some larger algae that have tissues that are easily visible, but those that dominate are the flowers plants (angiosperms). Macrophytes, like all other photoautotrophic organisms, use the solar energy to assimilate inorganic carbon from the atmosphere to produce organic matter, which subsequently provides the energy source for heterotrophy (animals, bacteria and fungi). As a result of the ample light, water and nutrient supply in wetland, the primary productivity of these ecosystems are among the highest recorded in the world (Westlake, 1963; Brix, 1994; Wetzel, 2001; Cronk and Fennessy, 2001 - in Brix, 2003).

Most constructed wetland has been designed to treat domestic or municipal wastewater but actually they are used for any kind of industrial and agricultural wastewater. This system consists generally of a monoculture or polyculture of vascular plants in tanks, lagoons or little deep ditches, with a retention time longer than conventional systems. The macrophytes growing in wetlands may be classified in the following major groups according to their life form:

- a) *Emergent aquatic macrophytes*: These are the dominant life form in wetland that are rooted in the soil with stems, leaves (photosynthetic parts) and reproductive organs above the water column, with 50 to 150 cm depth. In general and besides the aerial stems and leaves there is an extensive root and rhizome-system.

Both terrestrial and emergent aquatic plants obtain carbon from the atmosphere in the form of free carbon dioxide, which enters the stomata on the leaves. Most aquatic plants, adapted to grow in a water-logged or submersed substrate, possess unique adaptations for transporting atmospheric gases. One of these adaptations is represented by a system of interconnected tubes or gas-filled spaces that permeate most submerged stems, petioles and leaf blades called *aerenchyma*. These spaces allow oxygen and other gases to flow freely and be transported from the upper parts of the plant to the roots and rhizomes. This oxygen leakage from the roots creates oxidised conditions in the otherwise anoxic substrate and stimulates both aerobic decomposition of organic matter and growth of nitrifying bacteria (Campbell, Craig & Ogden, Michael – 1999). *Phragmites australis*, *Typha* spp, *Iris pseudacorus*, *Canna* spp, *Cyperus papyrus* and *Oryza sativa* are examples of emergent macrophytes.

- b) *Submerged aquatic macrophytes*: With the possible exception of flowering, these plants spend their entire life cycle beneath the surface of the water. Most of all are rooted in the substrate, although there are several rootless species that float free in the water column. In submerged species, all photosynthetic tissues are normally underwater and take up dissolved oxygen and carbon dioxide from the water column. Others are able to use dissolved bicarbonate in photosynthesis. Rooted submerged species acquire the majority of their nutrients from the sediments, although some nutrients, particularly micronutrients, may be absorbed from the water column (Barko and Smart 1980, 1981b, in Cronk, J.K. and Fennessy, M.S., 2001). Rootless species are dependent on the water column as their sole nutrient source. Species like *Elodea Canadensis*, *Litorella uniflora*, *Egeria densa* and *Potamogeton* spp. are examples of submerged macrophytes.

- c) *Floating-leaved aquatic macrophytes*: This group includes species which are rooted in the substrate, like *Nuphar* spp., and species which are freely floating on the water surface, like *Eichhornia crassipes* or *Pistia stratiotes* and *Lemna* spp.. The freely floating species are highly diverse in form and habit, ranging from large plants with rosettes of aerial and/or floating leaves and well-developed submerged roots, like *Eichhornia crassipes* or *Pistia stratiotes*, to very small surface-floating plants with few or no roots, like *Lemna* spp..

In this group *Eichhornia crassipes* is one of the most productive photosynthetic plants in the world. It has been estimated that 10 plants could produce 600 000 more during an 8 month growing season and completely cover 0.4 ha of a natural freshwater surface (Penfound and Earle, 1948, in Vymazal, 2003). This rapid growth is the reason that *Eichhornia crassipes* is a serious nuisance problem in southern waterways, but these same attributes become an advantage when used in a wastewater treatment system, though frequent harvests are necessary.

The aquatic macrophytes cultured in such treatment systems perform several functions, including assimilating and storing of contaminants, transporting oxygen to the root zone and providing a substrate for microbial activity (Brix, 2003). This system is a complex filter, in which macrophytes and physical, chemical, and microbial components integrate an effective system (Wood & McAtamney, 1996).

Besides the functions related to the wastewater treatment, macrophytes vegetation is also important as wildlife support especially in large systems. It also has an aesthetic value in small systems such as single houses, hotels, etc. It is possible to select nice-looking plants namely the *Iris pseudacorus* or other with flowers, making the sewage treatment system an attractive one. In this integrated systems, the use of native species has the advantage of being adapted to the local climate (Kadlec, 2003).

In Portugal the first full-scale constructed wetland was built at Estarreja in 1993 and was designed for industrial wastewater treatment. In 1997 at Pinheiro da Cruz near Setúbal, it was built the first full-scale system for domestic wastewater treatment. Recently, small systems for small users and individual residences were constructed. All constructed wetland in Portugal use emergent aquatic macrophytes and the most of them are used for secondary treatment of municipal or domestic sewage. The species more used are: *Phragmites australis* and *Thypha latifolia* (Dias & Martins Dias, 2003).

Once in Portugal there are many autochthones macrophytes (namely *Iris pseudacorus*, *Phragmites australis* e *Thypha latifolia*) it is important to study their efficiency in urban and also in industrial and agricultural wastewaters treatment in order to expand the scope of those applications in our country.

In this context studies have been conducted to test the efficiency of autochthones plants naturally occurring in Portugal to treat different wastewaters. This work focuses the case of an urban effluent treatment with *Phragmites australis* from Sado riverbanks and *Iris pseudacorus* from Mondego riverbanks.

Methods

Three tanks (60cm x 60cm x 40cm) were prepared with two layers: 5cm gravel and 25cm sand as physical support. The plants used were taken in natural ambience: *Phragmites australis* from Sado riverbanks and *Iris pseudacorus* from Mondego riverbanks.

This experiment was carried out in a greenhouse under monitored conditions. Eight young shoots of *Phragmites* and *Iris* were collected, cleaned and acclimated in tank with natural water before the experiment. Two tanks were planted with *Phragmites* (T1) and *Iris* (T2) filled with municipal wastewater. One unplanted tank filled with wastewater served as a control for the system (T3).

The experiment run for 14 days, in Spring, and water samples were collected from the bottom of T1, T2, T3 tanks at day 0, 1, 2, 3, 4, 6, 8, 10 and 14 for oxidability determination (SMEWW, 1998) and at day 0 and day 14 for the other parameters: pH and total suspended solids (TSS) (SMEWW,

1998), biochemical oxygen demand after 5 days (BOD₅) (adapted from SMEWW, 1998), chemical oxygen demand (COD) (ISO 6060:1989), nitrogen (NO₂) (ISO 6777:1984), ammonium nitrogen (NH₄) (adapted from SMEWW, 1998), total Kjeldahl nitrogen (TKN) (ISO 5663:1997), phosphorus (P) (SMEWW, 1998), phosphates (P₂O₅) (SMEWW, 1998) and anionic surfactants (SMEWW, 1998).

Ecotoxicological assessment was performed for samples from T1, T2 and T3, at day 0 and day 14, using Microtox test (Microbics, 1992), Daphnia test (ISO 6341:1996) and Lemna test (ISO/DIS 20079:2003). Ecotoxicological results are presented as % of effect for maximum concentration.

Results and discussion

Results are presented in Figure 1 and Table 1. A decrease in oxidability values was observed during the experiment. After 24 hours oxidability values decreased deeply for all tanks. After 14 days, this decrease was greater, *circa* 90%, for planted tanks (T1 and T2) than for the control tank, where a decrease of 72% in oxidability was measured, meaning an additional removal of 18% in macrophyte planted tanks.

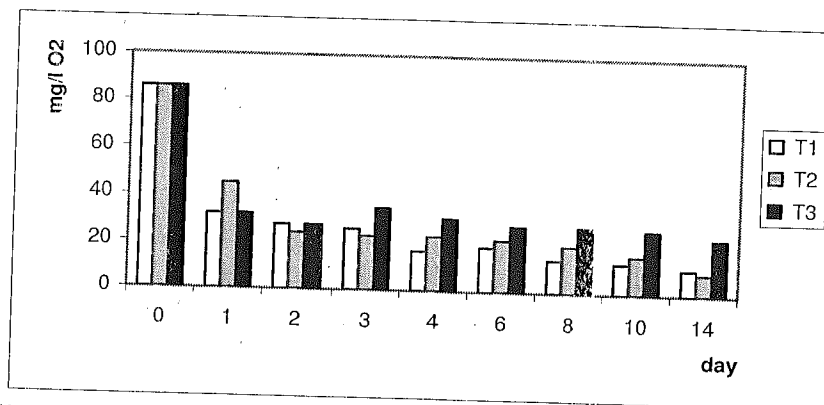


Fig. 1 – Oxidability values for samples taken from tanks T1, T2 and T3 during the experiment.

pH values didn't show major changes during the experiment either for the control tank or planted tanks.

TSS values dropped deeply in all tanks. Organic matter - BOD₅ and COD, showed a removal higher than 90% for all tanks, and a greater removal (10 – 13 %) was observed for planted tanks.

Phragmites appears to be more efficient in terms of organic matter removal while *Iris* was more efficient in the removal of nutrients. An important feature was the removal of TKN by the planted tanks (90% and 95% for T1 and T2 respectively) while the unplanted tanks didn't show any TKN removal. At day 14, the lowest value of phosphate was observed in *Iris* planted tank.

Anionic surfactants, usually present in urban wastewaters, were removed by 98% in planted systems, while the removal in unplanted system was of 91%.

The integrated ecotoxicity assessment showed a decrease in toxicity, particularly for planted tanks.

The use of inorganic material, like sand and gravel, for vegetation support provides a large superficial area for microbial community development (Novais & Martins Dias, 2003). The joint

action, of vegetation and microorganisms, can be responsible for an added efficiency in this wastewater treatment system.

Table 1. Physico-chemical and ecotoxicological values for samples taken at days 0 and 14 in control (T3) and planted tanks (T1 and T2).

Parameter	Day 0	Day 14		
		T1	T2	T3
pH	7.5	7.2	7.3	7.3
TSS (mg/l)	389	3	9	7
BO ₅ (mg/l O ₂)	295	<10	<10	31
COD (mg/l O ₂)	673	43	51	130
Oxidability (mg/l O ₂)	86	11	9	24
NO ₂ (mg/l)	0.04	0.34	<0.0	<0.0
			1	1
NH ₄ (mg/l)	46	3.5	<1.0	17
TKN (mg/l)	54	4.9	2.3	54
P ₂ O ₅ (mg/l)	8.3*	0.11	0.04	0.25
Anionic surfactants (mg/l)	6.4	0.10	0.14	0.56
Microtox (% effect)	100	0	0	14
Daphnia (% effect)	60	0	0	0
Lemna (% effect)	73	38	33	52

* Total P

Conclusions

The use of plants for the treatment of urban wastewaters presents advantages either in physico-chemical parameters reduction or in toxicity removal. Moreover in aesthetic terms the use of flowering plants like *Iris* can be an interesting solution in urban management.

References

- Brix, H. (2003). Plants used in Constructed Wetlands and Their Functions. In: Proceedings of the 1st International Seminar on The use of aquatic macrophytes for wastewater treatment in constructed wetlands. FCG, 8-10 Maio, Lisboa, V. Dias and J.Vymazal (Ed), Lisboa, pp. 81-109.
- Campbell, Craig & Ogden. Michael (1999). Constructed Wetlands in the Sustainable Landscape. Edited by John Wiley & Sons, Inc. in the USA. ISBN 0-471-10720-4, 270 pp.
- Cronk, J.K. and Fennessy, M.S. (2001). Wetland Plants: Biology and Ecology. Edited by Lewis Publishers. Printed in USA. ISBN 1-56670-372-7. 463 pp.
- Dias, V.N. and Martins-Dias, S. (2003). Constructed Wetland for Wastewater Treatment: The Portuguese Experience. Proceedings of the 1st International Seminar on The use of aquatic macrophytes for wastewater treatment in constructed wetlands. FCG, Lisboa, V. Dias and J. Vymazal, Lisboa, pp. 467-492.
- ISO (1984). Water Quality – Determination of nitrite -- Molecular absorption spectrometric method. ISO 6777. International Standard Organization, Paris.
- ISO (1989). Water Quality – Determination of Chemical Oxygen Demand. ISO 6060. International Standard Organization, Paris.
- ISO (1996). Water Quality – Determination of the inhibition of the mobility of *Daphnia magna*

- Straus (Cladocera, Crustacea)- Acute toxicity test. ISO 6341. International Standard Organization, Paris.
- ISO (1997). Water Quality – Determination of Kjeldahl nitrogen -- Method after mineralization with selenium. ISO 5663. International Standard Organization, Paris.
- ISO (2003). Water Quality – Determination of toxic effect of water constituents and wastewater to duckweed (*Lemna minor*) – Duckweed growth inhibition test. ISO/DIS 20079. International Standard Organization, Paris.
- Kadlec, R.H. (2003). Status of Treatment Wetland in North America. Proceedings of the 1st International Seminar on The use of aquatic macrophytes for wastewater treatment in constructed wetlands. FCG, Lisboa, V. Dias and J. Vymazal (Ed), Lisboa, pp. 363-401.
- Microbics (1992). Microtox Manual – A Toxicity Handbook; Microbics Corporation, Inc.: Carlsbad, CA. Vols.I-IV.
- Novais, J., and Martins-Dias, S. (2003). Constructed Wetland for Industrial Wastewater Treatment contaminated with nitroaromatic organic compounds and nitrate at very high concentrations. Proceedings of the 1st International Seminar on The use of aquatic macrophytes for wastewater treatment in constructed wetlands. FCG, Lisboa, V. Dias and J. Vymazal, Lisboa, pp. 277-288.
- Vymazal, J. (2003). Types of Constructed Wetlands. Proceedings of the 1st International Seminar on The use of aquatic macrophytes for wastewater treatment in constructed wetlands. FCG, Lisboa, V. Dias and J. Vymazal, Lisboa, pp. 35 - 79.
- Wood, R.B. and C.F. McAtamney (1996). Constructed wetland for wastewater treatment: the use of laterite in the bed medium in phosphorus and heavy metal removal. *Hydrobiologia*, **340**: 323 –331.
- Standard Methods for the Examination of Water and Wastewater (1998). 20th Edition. Edited by L.S. Clesceri, A.E. Greenberg, A. D. Eaton. APHA, AWWA, Water Environment Federation. USA.