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NOMBRE DE AUTORES

Carlos A. Arias, Hans Brix & Mónica F Garza.

NOMBRE Y DIRECCIÓN DE LAS INSTITUCIONES

Department of Biological Sciences, University of Aarhus, Ole Worms Allé, Building 135, 8000 Aarhus C., Denmark

NÚMERO DE TELÉFONO, FAX Y E-MAIL
Tel: (+45) 8942 4713
Fax (+45) 8942 4747
Email: carlos.arias@biology.au.dk, hans.brix@biology.au.dk

ALTERNATIVES FOR PHOSPHORUS REMOVAL IN SUBSURFACE FLOW CONSTRUCTED WETLANDS

Carlos A. Arias, Hans Brix & Mónica F Garza.
Department of Biological Sciences, University of Aarhus, Denmark

ABSTRACT
Constructed wetlands have overcome the experimental phase and today are referred as reliable, robust and appropriate technology for the management of wastewaters. The specific removal capacity of pollutant can be improved depending on design and the physical features of the system. However, phosphorous removal by constructed wetlands seems to be a limiting pollutant and up to now it has proven elusive. P removal efficiency in subsurface flow constructed wetlands varies with time and is dependant on physicochemical reactions and operation management. The paper presents the possible strategies available for P-removal such as plant harvesting media adsorption and chemical dosing that have been evaluated in the laboratory as well as systems treating domestic wastewater in single households in Denmark. The results show the difficulties when selecting a definite and reliable solution for P removal, and present applicable strategies in order to mitigate the effect of P rich discharges.
KEYWORDS: Adsortion, chemical precipitation, filling media, *Phragmites australis*, vertical flow.

ALTERNATIVAS PARA LA ELIMINACION DE FOSFORO EN HUMEDALES ARTIFICIALES DE FLUJO SUBSUPERFICIAL

RESUMEN
Los humedales artificales dejaron de ser sistemas experimentales y hoy por hoy son una solución confiable, robusta y apropiada para el manejo de agusas residuales domésticas. La capacidad de eliminación de contaminantes puede ser potenciada deacuerdo al diseño o a las características físicas de los sistemas. Sin embargo, la eliminación de fósforo usando humedales de flujo subsuperficial es limitada y la solución no parece ser simple ni satisfactoria, pues la capacicidad de eliminación de P varía en el tiempo, no es consistente y depende de múltiples factores fisico-químicos e hidráulicos. Esta comunicación presenta las posibles estrategias a seguir cuando se requiera eliminar P. Las alternativas ensayadas a nivel laboratorio y campo en Dinamarca incluyen la cosecha de material vegetal, la adsorción de P al medio filtrante y la precipitación química. Los resultados obtenidos demuestran las dificultades operativas que se presentan al selecionar una solución confiable y definitiva para obtener la eliminación de P de aguas residuales de uso doméstico.
PALABRAS CLAVE: Adsorción, precipitación química, medio de relleno, *Phragmites australis*, flujo vertical.

1. INTRODUCTION

Danish environmental protection action plan of 1997 (Ministry of Environment and Energy 1997) states that sewage generated in the rural areas have to be treated to specific levels (e.g. removal of organic matter, nitrification and removal of P) depending to the environmental conditions of the receiving waters or to the vulnerability of the region. This new plan also recommends the development of technologies for accomplishing the removal goals and the production of construction guidelines for the systems developed. Due to the experience and certainty of the capacity to remove pollutants, constructed wetlands were considered for the treatment of domestic wastewater from isolated households. The capacity of these systems to remove suspended solids organic matter and even to reduce total nitrogen is well documented (Cooper, P. 1999; Cooper, P. 2001; Brix, H. et al. 2002; Weedon, C. M. 2003; Cooper, P. 2003; Arias, C. A. et al. 2005). However,, the capacity for removing P has been regarded as limited, difficult, inconsistent and short termed. Research experiences suggest different technical approaches for removing P to meet local discharge demands. Among the known strategies for P-removal in subsurface flow constructed wetlands are: the harvesting of emergent vegetation, the construction of the wetland beds using material with high Ca content to enhance P adsorption and/or precipitation, the establishment of external filters in order to retain P before final discharge and the implementation of independent chemical dosing systems to precipitate the P. Several of these strategies have been evaluated in Denmark, and even though they show P-removal potential, the amount removed and performance sustainability varies and consequently affects their applicability as P removal solutions, given that Danish P effluent demands are strict (Brix, H. 1994; Brix, H. et al. 1996; Brix, H. 1997; Arias, C. A. et al. 2003; Groth E and Hansen K.L. 2003; Arias, C. A. and Brix, H. 2004).

2. METHODS AND RESULTS

Loading in constructed wetlands

Constructed wetlands, as any other treatment system used for handling wastewaters, will receive waters with a variety of pollutants in nature and concentration. In order to assess the loading of contaminants the Danish EPA in its design guidelines states that the expected pollutant load from domestic sources is dependant on the number of person equivalents (PE) that the systems serve. As such for constructed wetlands the Danish EPA (2004), quantifies the influent pollutants for domestic wastewater waters as a function of the PE served and the gr d^{-1} of the specific contaminant measured so that the load should be calculated by multiplying the number of PE times a given load for each of parameters as follows: Average daily water usage is 150 L d^{-1} per PE, organic matter evaluated as BOD_5 is 60 g d^{-1} per PE, the total nitrogen load is 13 g d^{-1} per PE, and the total P load is 2.5 g d^{-1} per PE. According to the P loading suggested by Danish EPA guidelines, the amount of P produced by a person per year ads up to around 1 kg P y^{-1}. This amount shows, that the P loading in constructed wetlands serving several PE is considerable and great demand is exerted on the system, that according to the Danish law is expected to eliminate at least 90% of the influent total P and consistently produce effluents with concentration below 1.5 mg P L^{-1}. Simultaneously the system must maintain high performance in the removal of the other typical domestic contaminants (TSS, BOD_5 and total nitrogen) before the final discharge of treated waters to the environment.

P removal strategies

Plant harvesting

Plants in constructed wetlands are an integral part of the system and are essential for the improvement of water quality (IWA 2000). Plants are known for “cooperating” to the removal of a variety of contaminants including, organic matter, nitrogen, phosphorus and heavy metals. Plant uptake is considered important, but in order to achieve any long term removal, the plants have to be harvest before the stored pollutants are returned to the wetland due to natural decomposition. Therefore harvesting is a possible approach when one must remove certain pollutants from a wetland. The removal of P by harvesting the emergent vegetation in a subsurface flow constructed wetland is limited by the P stored in the biomass that grows above ground, since below ground material is impossible to access and therefore unavailable for harvesting. According to Brix and Schierup (1989) these accessible biomass ranges between 3 and 15 g P m^{-2} y^{-1}. Vymazal (2004) presents data gathered from different constructed wetlands, locations and different plants where he places the above ground P standing stocks in the range of 0.1 to 11 g P m^{-2} y^{-1}. Another possibility that must be considered is several cuts during the growing season and according to Karunaratne (2004), for *Pragmites australis* the removal can be of around 200 g P m^{-2} yr^{-1}. Since the recommended area for constructed wetlands varies according to the type of wetland selected and the wastewater characteristics and the typical surface required range is between 3 and 20 m^2 PE^{-1} a simple calculation and using the most optimistic conditions reported for above ground P removal (15 g P m^{-2} yr^{-1}) and the largest typical surface per PE (20 m^2), the total P removal capacity comes up to around 300 g P yr^{-1}. Considering that the usual P production of P in wastewaters is of about 1 kg PE^{-1} yr^{-1}, shows that harvesting alone can not be the only P removal strategy if P removal is required, since the maximum P removed by this sole method only represents 30% of the average P entering a conventional constructed wetland domestic wastewater treatment system. Additional draw backs for using harvesting as a P removal strategy in constructed wetlands is the fact that the vegetative period of the plants is not uniform in temperate climates and while in the growing season the P removal potential is at is highest in spring, in winter, when the plants are wilted, the P removal is low. Additionally, harvesting plants also demands direct intervention on the beds, risking the modification of the construction characteristics of the system, and/or damaging the hydraulic structures and modifying the surface of the beds.

Removal of P by sorption processes in the bed

Another possibility that could be considered when designing and constructing a subsurface flow constructed wetland for wastewater treatment is taking advantage of chemical composition of the media used for filling the bed. It is well documented that P can be removed by adsorption and/or precipitation reactions with the media if the media used is rich in metals such as Ca, Al, Fe and Mg. (Johansson, 1999; Drizo, 2002). The P removal capacity will depend in several factors including the nature of the media used, the physco-chemical characteristics of the material, the water characteristics and the hydraulic regime. Subsurface flow constructed wetlands in operation have shown that P-removal by the media is often high, right after installation of the system, but tends to decrease with time, as the substrate saturates as the P-sorption capacity is used up and the growth of biofilm around the media grains limits the contact between the wastewater and the media and therefore limits the chemical reactions between them and reduce the removal capacity of the media.

The potential of P removal by the media has been evaluated using constructed wetlands in operation, pilot plant studies and laboratory tests. The first type of test has the inconvenience that it cannot provide results from the isolated effect of the media for P removal since all the other processes occur simultaneously to P binding. On the other hand, most of the pilot plant and laboratory experiments are short termed and often done using either artificial wastewater or P-spiked water, which limits the applicability of results and in the field. A large variety of material has been tested and it includes natural media as sand and gravels as well as artificial materials with the necessary hydraulic conditions to guarantee proper operation.

Since the most common media used for filling the beds on constructed wetlands is a combination of sands and gravel, the capacity for P removal of the media varies with the nature of the material and there is not a definite way of calculating how much P can be retained by the media. The tendency is to use those sands rich in chemicals that could bind P, these means high contents of Ca, Mg, Fe and even Al. These chemical characteristics are more likely to be found in sea shell sands and therefore emphasis has been placed on the evaluation of their potential. After the evaluation of a large variety of sands, both in the laboratory and in the field shows that the most optimistic calculations of the potential are that they can retain around 2 to 3 kg P m^{3} (Arias and Brix 2004). Once again a simple calculation shows that the media capacity would be totally saturated in a period of around three years. If P removal should be maintained in the long term, a change of the media would be required. But since all wastewater treatment is constructed with a larger life expectancy, the option of replacing the bed every time the sands are P saturated makes the option economically not viable. Even though sands are capable of removing P from domestic wastewaters, relying exclusively on them should not be the option since the capacity is surpassed by the high concentrations of phosphorus in the influent wastewaters.

The use of artificial media has also been tested and great deal of industrial resources has been inputted in this alternative. The same approach is used and the intention is to fill the bed with an artificial media capable of retaining the influent P. A good example of this method is the use of Filtratlite-P ® filter beds being developed and implemented in the Scandinavia countries. The systems demand the construction of treatment in two sections: The first section should take care of the biological treatment of the wastewater, and is followed by a second section mainly intended for the retention of P. Filtratlite-P ® is an specific LECA media capable of retaining P and according to Jensen et al (2005) the capacity of this material is around 12 kg P m^3, which suggests that in order to achieve a sustained removal of P through the life expectancy of the system (xx years?) with typical P influent concentrations, a volume of around 8 m^3 per PE of Filtratlite-P ® material should be needed.

In general it can be said that using the bed as sink for P removal might have the inconvenience of limiting the life expand of the beds, since once the P removal capacity is used the bed can no longer provide reliable and effective P elimination. Even though the elimination of other pollutants occurs, the system would no longer be accepted due to the limited P removal..

External P removal Filters

Since the replacement of a whole bed can create economic as well as logistic problems another option available for the removal of P is the use of external filters built specifically to remove P. The concept involves the construction of an external structure (different form the bed) filled with a material with high capacity to bind P. The material should be replace as the removal efficiency of the P filtering media decreases. This P removal solution tries to solve the problem of the decreasing capacity of media filling the bed and should maintain just by replacing a small amount of material, reducing operation costs and minimising the intervention on the beds.

Most of the material evaluations have taken into account the results obtained from typical bed filling media (sands and gravels), and with artificial materials such as LECA (Light Expanded Clay Aggregates), shredded metals and sea shells. Brix *et al* (2001) reported a material with promising capacity for the removal of P, and with laboratory tests of around 25 kg P m^3. Further tests with the material showed that under normal wastewater operation conditions the capacity was reduced and the occurrence of some operational problems. Modifications were made to avoid operational problems but unfortunately the material is no longer available in the market. Similar materials have been tested but the results obtained have not reached the capacity needed if an external filter is to be placed as the sole solution for P removal

Chemical dosing

The addition of coagulants in order to eliminate pollutants is a common and reliable practice when treating wastewaters. The use of this chemical alternative for P removal in constructed wetlands is hardly documented and only recently has been acknowledged as a possibility for the control of P discharges. There is a broad choice of chemical products in the market that can be selected for the coagulation and precipitation of P. The chemical selected for the P removal will depend of the characteristics of the wastewater, local effluent discharge restrictions and the location of the chemical dosing system within the plant. Since constructed wetlands are meant to be low technology systems, the coagulant injection systems must follow the same philosophy and it should be simple, trouble free but reliable. As mentioned before, the need of complying with effluent discharge has forced to rely in chemical dosing;

the current approach is to install the dosing system close to the primary treatment so that the coagulant precipitates the P and is eliminated as primary sludge. Since the removal occurs at this early stage of the treatment the coagulant of choice is Polyaluminium-chloride (commercially known as PAX 14) stable under anoxic conditions. Stoecheometric calculations suggest that the amount of chemical needed per PE under Danish typical conditions should be around 3 L PE^{-1} per year but since the P is to be removed at an early stage in the treatment, there are additional pollutants that can react with the chemical, reducing the efficiency of the process. Laboratory and field tests tend to suggest that in order to meet the local demands the volume of chemical injected per year should be increased to around 5 L PE^{-1}. A critical issue for the reliability and efficiency of the system is to provide and accurate and effective chemical dosing. The solution chosen has been the installation of an airlift pump at the 3rd chamber of the primary treatment that recirculates water back to the entrance of the primary treatment. During the recirculation the chemical is accurately injected by means of a peristaltic pump and mixed with the water thanks to the effective turbulence created by the airlift. Once the reaction takes place P is coagulated and consequently precipitates and is removed as primary sludge. If chemical dosing is kept under the previously stated volumes, there shouldn't be large generation of sludge and no environmental toxic effects are expected.

3. CONCLUSSIONS

Efficient and reliable removal of phosphorus in subsurface flow constructed wetland systems can only be maintained in the long term by supplementing the constructing wetland system by a chemical dosing system. Despite numerous studies on varies natural and artificial potential medias, it has not been possible to identify a material that has a sufficiently high binding capacity for phosphorus. The best materials will remove phosphorus for a few years only, but at the same time the present tendency is also to minimize the needed surface area in order to decrease costs, which would at the same time reduce the P removal capacity. Binding of phosphorus to the media and also uptake by plants will remove some phosphorus. This can be important for removal robustness, particularly when the majority of the P is removed prior to the wetland e.g. by chemical precipitation.

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