Elimination of micropollutants using engineered constructed wetlands – a laboratory scale study

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1. Introduction and motivation

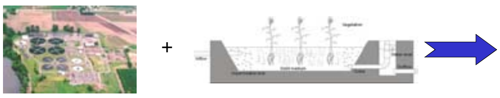
In Switzerland, a new standard for wastewater treatment plants (WWTP) – 80% reduction of micropollutants from raw sewage – is under consideration. Five substances have been proposed as target compounds: *Diclofenac*, *Carbamazepine*, *Mecoprop*, *Sulfamethoxazole* and *Benzotriazole*. Although very efficient and reliable, advanced treatment technologies for traditional WWTPs – such as ozonation – are expensive and difficult to implement on relatively small WWTPs, of which there are many in Switzerland. To tackle this problem, we propose to develop a promising technology for supplemental treatment of wastewater: **E**ngineered subsurface flow **C**onstructed **W**etlands (**ECW**s).

Classical constructed wetlands (CW) are passive systems, using natural processes to transform and remove contaminants from wastewater. In this work, we have developed and proposed a different design paradigm, i.e., to combine in a single ECW both natural processes (as in CWs) and ad hoc engineered treatments.

The resulting system – an ECW – combines the strengths of both natural and engineered processes, that is, it will be efficient and reliable, with low maintenance and running costs.

A laboratory scale study was performed to develop a combination of treatments able to achieve the target elimination rate for micropollutants. Based on literature results, two processes – direct photolysis and adsorption by light expanded clay aggregates (LECA) – were expected to remove more than 80% of the target compounds. Batch experiments were conducted to test the removal efficiency of each process alone. A laboratory-scale ECW combining the two removal treatments with biodegradation was subsequently performed to evaluate whether the combined processes could enhance the degradation rate.

2. Engineered Constructed Wetlands as advanced treatment

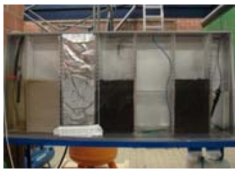


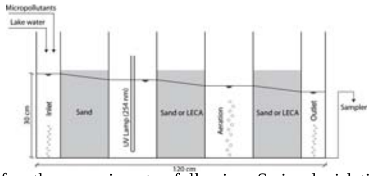
Satisfaction of Swiss legal requirements, water reuse

« Classical » wastewater treatment plant *Engineered constructed wetlands*

- Pharmaceuticals are often poorly degraded in wastewater treatment plants (WWTPs). They are persistent substances in the aquatic environment, are easily bio-accumulated, and may represent an environmental risk. Advanced water treatment is used to eliminate pharmaceuticals from water. One cost-efficient treatment method consists of treatment of pre-treated wastewater by engineered constructed wetlands
- Goals of the project:
  - To implement an advanced treatment to traditional WWTPs, in order to eliminate micropollutants, in accordance with Swiss legal requirements and to allow water reuse
  - To test different individual processes occurring in a laboratory-scale CW to evaluate systematically their potential for micropollutant elimination
  - To couple the processes in at the laboratory scale to assess the potential of ECW for micropollutant degradation

3. Experimental setup

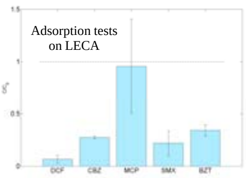




- Five micropollutants were considered for the experiments, following Swiss legislation: *Diclofenac (DCF), Carbamazepine (CBZ), Mecoprop (MCP), Sulfamethoxazole (SMX) and Benzotriazole (BZT*). Analyses were conducted on a Waters UPLC MS/MS system
- The system was initially inoculated and biomass was allowed to grow for some time
- Adsorption batch tests were conducted following OECD guidelines with three different materials typically used in CWs: pure sand, light expanded clay aggregate (LECA) and Filtralite®
- UV photodegradation tests were conducted in a laboratory reactor (15W low pressure UV lamp), the same lamp was used for the laboratory-scale ECW
- A laboratory-scale ECW (average residence time: 6 hours) was used to investigate the combined processes, including water flow. Constant micropollutant injection (3 days) was followed by a wash-out period (4 days); samples were regularly collected over the whole period

4. Results

Adsorption processes - batch



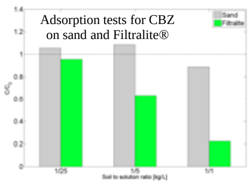
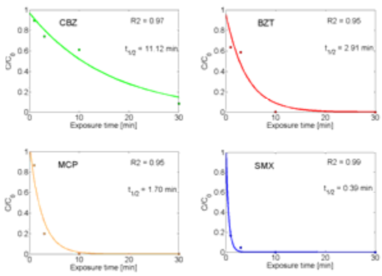


Figure on the ***left*** illustrates the relative concentration of the five micropollutants after adsorption onto LECA. Except for MCP, LECA is an efficient adsorption medium (C/C_0 < 30%) for the studied substances

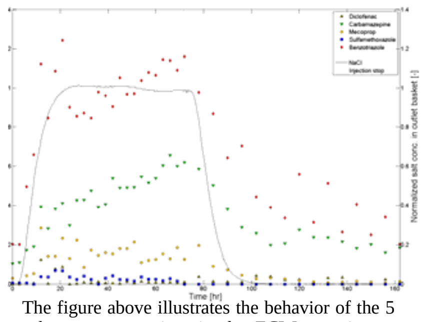
Figure to the ***right*** reports the relative concentration of CBZ after adsorption onto sand and Filtralite® in batch tests, considering 3 soil-to-liquid ratios. The importance of this parameter is clearly demonstrated. Pure sand is not a suitable substrate for CBZ adsorption

UV Degradation - batch



After 10 minutes of exposure to UV light the 5 pharmaceuticals show a rapid decay (C/C_0 < 10%). CBZ is the most recalcitrant compound, DCF (not illustrated) is rapidly photolyzed (< 1 min)

Dynamic investigation in the lab-scale ECW



The figure above illustrates the behavior of the 5 substances over time in the ECW experiment. Sand was the substrate used in the 1st compartment, while LECA was used in the rest

Micropollutant removal rates are consistent with the results of adsorption and UV photolysis batch experiments, illustrating the potential of ECW concept as an advanced treatment. Limited biodegradation was observed.

5. Discussion and Conclusions

- The target elimination of micropollutants in WWTPs (80%) requested by the Swiss legislation can be achieved for DCF, SMX and MCP. CBZ removal was less (5-30%), and no elimination was observed for BZT
- Only limited of experimental conditions and removal processes were studied
- Adsorption on a suitable substrate is an appealing process for micropollutant elimination. LECA showed good removal efficiency
- The addition of the engineered UV degradation step is beneficial. An advantage of CW is that filtration through the porous substrate reduces turbidity and increases photolysis efficiency. The potential risk of problematic metabolites can be attenuated by further filtration through downstream compartments
- Energy needs for an ECW system (UV lamp and air bubbling system) were evaluated. It was found that solar panels can sustain system operation in most conditions

Future work

- Detailed studies on adsorption materials, especially on the saturation of the adsorption material and the risks of desorption
- Two processes, i) biodegradation and ii) effect of vegetation, have not been investigated in detail so far. Biodegradation is investigated in a recently started PhD project
- Extrapolation to other micropollutants
- Validation of a transport and reactive model for micropollutants degradation in ECW for the optimization of the system design
- Installation of a pilot ECW system as advanced treatment at the outlet of a real WWTP to test the concept under real conditions

Engineered Constructed Wetlands = promising sustainable system for the elimination micropollutants from WWTPs effluents.

		DCF	CBZ	MCP	BZT	SMX
Classical CW	Sand					
Engineered CW	Sand					
	LECA					

	< 5 %	No removal rate
	5 % - 30 %	Poor removal rate
	30 -70 %	Moderate removal rate
	70 – 95 %	High removal rate
	>95 %	Very high removal rate
	No information	