Simulation of anaerobic processes in subsurface flow constructed wetlands

Introduction

Constructed wetlands (CWs) provide a natural way for simple, inexpensive, and robust wastewater treatment. In order to use CWs as hybrid CWs, their flow level is visible, and water flows either horizontally or vertically through the porous filter media. A large number of physical, chemical, and biological processes occur in parallel and influence each other. Detailed understanding of CW functioning is therefore crucial. CWs have long been seen as "black boxes" where wastewater enters and treated water leaves the system.

Numerical models that describe the transformation and elimination processes in CWs are a promising tool to get a better understanding of the processes in CWs. Until now, very few models to simulate removal processes in subsurface flow CWs have been developed (Langenbrugger, 2008). Of these models, several are applicable to horizontal flow (HF) CWs, as they only consider saturated water flow using a single approach. For modelling vertical flow CWs with intermittent loading, transient variably-saturated flow models are required. Due to the intermittent loading, these systems are highly dynamic, adding to the overall complexity of the system.

In HF CWs anaerobic processes play a major role and have to be considered. Four model formulations have been developed ranging from a simple root only to complex reaction schemes. The pros and cons of these model formulations shall be discussed and ways to a general model suitable for describing anaerobic processes and their competition with aerobic, anoxic and plant-uptake processes in CWs shall be formulated.

Available model formulations

Four models have been considered for discussion which are described briefly:

- **Rousseau** (2005): Flow model based on tank-in-series approach; reaction model in matrix notation based on the mathematical formulation of the Activated Sludge Models (ASMs; Henze et al., 2000) with the description of aerobic, anaerobic and anoxic processes for carbon and nitrogen removal. Figure 1 shows simulated and measured COD and ammonium concentrations using Rousseau's model.

- **Brovelli et al.** (2007): Flow model based on MODFLOW coupled model ASM formulation including aerobic and anaerobic processes. Currently the model is being updated by introducing the Variably Saturated Flow (VSF) Process for MODFLOW (Thoms et al., 2006) and ii) by extending the biogeochemical reactions with anaerobic processes based on the model formulation by Maurer and Wittmann (2004).

- **Mena** (2006) proposed an extension of the CW2D model with anaerobic processes. The multi-component reactive transport module CW2D (Langenbrugger, 2001; Langenbrugger and Simanek, 2005) was developed to describe the biochemical transformation and degradation processes for organic matter, nitrogen and phosphorus in vertical flow CWs. Therefore no anaerobic processes have been included in the original model description. Figure 2 and 3 show simulation results for HF CWs using the original CW2D model formulation without anaerobic processes.

- **Ojeda et al. (2008):** Processes affecting solids, organic matter, nitrogen and sulphur are considered based on a simple model described by Van Cappellen and Gaillard (1996). The model was developed primarily for HF CWs, but because of the underlying flow model, it is also capable of simulating vertical flow CWs. Figure 3 and Table 1 show simulation results using Ojeda's model.

Comparison and discussion

The experience showed that the inclusion of anaerobic processes in the model is only important for high loaded systems. The reasons for this are: i) the modelled processes are limited to processes for which there is available reliable data (e.g., stoichiometry), ii) the time scale for the anaerobic processes is much longer than for the aerobic processes, and iii) the assumptions for the anaerobic processes are only valid for high loaded systems. Therefore no anaerobic processes have been included in the proposed model formulation.

- **Iron reduction:** Usually very low concentrations of Fe in regular urban wastewater (less than 2 mg/L). Therefore it is assumed that these processes play a minor role when treating domestic wastewater.

- **Methanogenesis on SA:** Biological sulphide oxidation plays a role in some constructed wetland systems. Therefore it is proposed to include these processes (occurs under aerobic and anaerobic conditions) in the model.

The full model formulation of the biokinetic model shall be presented at the 11th IWA Specialized Group Conference on "Wetland Systems for Water Pollution Control" 11-17 November 2008, Indore, India. The authors want to point out that there are a number of processes that have to be considered for the formulation of a full model for constructed wetlands:

- The model flow describing water flow in the porous media is of utmost importance; finite element or finite difference models shall be used for describing water flow.

- Influence of plants (growth, decay, deposition, nutrient uptake, root oxygen release, etc.)

- Transport of particles/suspended matter and the description of clogging processes.

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<th>Process</th>
<th>Biodegradation of glucose</th>
<th>Hydrolysis of cellulose</th>
<th>Ammonification</th>
<th>Denitrification</th>
<th>Sulphate reduction</th>
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**Table 1:** Percentage of COD removal by different microbial reactions included in the proposed model formulation

References


Fig. 1: Simulated and measured COD and ammonium concentrations in a HF CW. (Garcia et al., 2007: between day 50 and 90 no measured data on the influent and effluent COD)

Fig. 2: Comparison of measured data from tracer experiments to simulation results using different models (acc. to Mena, 2008).

Fig. 3: Simulation results for a HF CW using CW2D (top left: COD, top right: NH4-N; bottom right: NO3-N)

Fig. 4: Simulated dissolved COD (left) and ammonia (right) concentrations for different hydraulic loading rates. (Ojeda et al., 2007)

Table 1: Percentage of COD removal by different microbial reactions included in the proposed model formulation

Table 2: Comparison of the biokinetic processes included in the different models and process experiments that will be included in the proposed model formulation

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**References**

Langenbrugger, G. (2008). Environmental engineering division, Department of Hydraulics, Coastal and Environmental Engineering, Technical University of Catalonia, Jordi Girona 1-3, 08004 Barcelona, Spain. jlangen@enric.cat

Mena, J. (2008). Tratamiento de aguas residuales mediante sistemas subterráneos (Master Thesis submitted in partial fulfillment of the requirements for the Master of Science, University of California, Davis, USA)