Vertical flow constructed wetlands for the treatment of inorganic industrial wastewater

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I hereby declare that this thesis is my own account of my research and contains as its main content work that has not previously been submitted for a degree at any university.

X
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Abstract

The focus of this thesis is primarily on nitrogen removal and secondarily on heavy metal accumulation in unsaturated and saturated vertical flow constructed wetlands (VFCWs) treating inorganic industrial wastewater. This thesis is divided into an experimental component and a case study component. Three research themes are presented within the scope of this thesis. The first theme involves the study of nitrification and denitrification and the characterisation of the respective bacterial communities in unsaturated and semi-saturated VFCWs. The identification of functional bacteria with the aid of polymerase chain reaction (PCR) based molecular techniques and the effect of salinity (NaCl) on these bacterial groups is also contained within this theme. The second theme is the use of low cost carbon sources to improve denitrification and nitrogen removal in saturated VFCWs. The third theme of this study is the performance of large scale VFCWs operating at CSBP Ltd, a chemical and fertiliser manufacturer based in Kwinana, Western Australia. The performance of the systems is assessed in regards to nitrogen and heavy metal removal. This theme also covers design and operational recommendations for improved nitrogen removal.

Laboratory scale VFCWs planted with Schoenoplectus validus were used to assess the impact of increasing salinity (up to 40gNaCl/L) on nitrification and on ammonia oxidising bacteria (AOB). Ammonia removal above 90% could be achieved in the fresh and saline wetlands when these were operated under a hydraulic loading rate of 11cm/d. This represented a removal rate in the order of 12gNH₃-N/m²/d. The gradual increase in salinity to 40gNaCl/L did not impact ammonia oxidation whereas the sudden increase (shock load) to 30gNaCl/L negatively impacted ammonia removal in the short term. Investigation of the microbial populations by terminal restriction fragment length polymorphism (T-RFLP) performed along with cloning and sequencing revealed that the increase in salinity selected for Nitrosomonas sp Nm 107-like (Nitrosococcus mobilis) and Nitrosospira sp 9SS1-like (Nitrosospira multiformis) AOB while other groups were eliminated or only present in very low proportions.

Nitrification and denitrification were further studied and the AOB and denitrifying bacterial (DB) community analysed in unplanted, fresh and saline, semi-saturated VFCWs dosed with acetic acid as carbon source. The semi-saturated design allowed nitrification to occur in the unsaturated sand layer and denitrification to occur in the saturated drainage layer where organic carbon was added, resulting in a high nitrogen removal. Nitrogen removal rates were on average 13.6gN/m²/d and 12.7gN/m²/d for the fresh and saline systems, respectively. Total nitrogen removal was significantly higher in the fresh system than in the saline system. The presence of salt, however, did not impact nitrate or COD removal and similar nitrate and COD concentrations were obtained in both wetlands. The gram-negative DB were also similar in both wetlands and dominated by representatives of the α and β-proteobacteria.
The feasibility of using carbon rich wastewater from a soft drink manufacturer (COD = 70,000mg/L), as exogenous carbon source to improve denitrification and nitrogen removal in saturated VFCWs treating high nitrate wastewater was tested. The addition of the carbon rich wastewater significantly increased nitrate removal from 23% to 65% and total nitrogen from 53% to 76%. Neither effluent ammonia nor effluent COD were affected by the addition of the carbon rich wastewater. Combining industrial wastewaters to improve treatability has proven to be cost effective and good example of industrial synergy with both economical and environmental benefits.

The case study covered the full scale treatment wetlands at CSBP Ltd. Firstly, heavy metal distribution, nitrogen removal performance and the AOB were analysed in the 1.3ha saturated surface VFCW, which has been operational since 2004. Secondly, the design rationale of two parallel nitrifying VFCWs, 0.8ha each, commissioned at CSBP Ltd in 2009 is described and the results from the first year of operation analysed.

The distribution of bioavailable Cu and Zn in the top sediment layer followed a horizontal profile with significantly higher concentrations near the inlet pipe than at the farthest location. The average total Cu concentration in the sediment at the 2m location has reached the 65mg/kg trigger value suggested by the Interim Sediment Quality Guidelines (ANZEEC 2000), indicating that increasing Cu levels could become toxic to plants and bacteria. From September 2008 to October 2009, the overall NH₃-N and TN removal rates were 1.2gNH₃-N/m²/d and 1.3gTN/m²/d, respectively. The 1.3ha wetland was operated in a sequencing batch mode, receiving highly fluctuating batch volumes and nitrogen concentrations. The majority of AOB sequences obtained were most similar to *Nitrosomonas* sp., while *Nitrosospira* sp. were less frequent.

The two VFCWs added to the treatment train in 2009 were designed assuming an NH₃-N removal rate of 4.5gNH₃-N/m²/d. Monitoring of the first year of data revealed that the cells operated under hydraulic and mass overloads. Ammonia oxidation was slightly higher than initially anticipated with the overall removal rate for the new cells being 5gNH₃-N/m²/d. Since commissioning of the new cells ammonia discharges have been greatly reduced.

Overall, this thesis has demonstrated that vertical flow constructed wetlands can be effectively applied for the treatment of inorganic industrial wastewaters containing nitrogen. These systems have proven to harbour diverse salt tolerant nitrogen transforming bacteria, allowing them to operate reliably under varying salinities.
Abbreviations

AMO – ammonia monooxygenase
AOB – ammonia oxidising bacteria
BOD – biochemical oxygen demand
C – control
COD – chemical oxygen demand
CW – constructed wetland
DB – denitrifying bacteria
DO – dissolved oxygen
EC – electrical conductivity
FWS – free water surface
HF – horizontal flow
HLR – hydraulic loading rate
HRT – hydraulic retention time
NOB – nitrite oxidising bacteria
ORP – oxidation-reduction potential
OTU – operational taxonomic unit
PCR – polymerase chain reaction
SBR – sequencing batch reactor
SDW – soft drink manufacturer wastewater
SND – simultaneous nitrification and denitrification
T – treatment
TN – total nitrogen
TOC – total organic carbon
TP – total phosphorus
T-RFLP – terminal restriction fragment length polymorphism
TSS – total suspended solids
VF – vertical flow
VFCW – vertical flow constructed wetland
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