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HIGH-RATE AMMONIA REMOVAL IN AERATED ENGINEERED WETLANDS

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ABSTRACT

This paper summarizes results from two studies conducted at an engineered wetland pilot facility at Alfred College (Ontario, Canada). The pilot facility consists of an aerated, vertical downward saturated subsurface flow wetland (1.08 m^2 surface area, 0.83 m bed depth, 1.3 cm gravel media) with supporting feed tanks and equipment. The system can be heated or cooled to control operating temperatures. The first study involved nitrification of domestic wastewater for the Township of North Glengarry, Ontario. The system was operated at a hydraulic loading rate of 33 cm/d and nominal hydraulic retention time of 1.2 days. The observed volumetric 2 TIS rate constant averaged 10.0 day^{-1} at 25°C and 8.4 day^{-1} at 6°C. The calculated θ factor was 1.02, which is comparable to literature values (1.04). The second study involved nitrification of mine process water from the Rosebel Gold Mine (Suriname, South America). The system was operated at 25°C, with a hydraulic loading rate of 12.9 cm/d and a nominal hydraulic retention time of 6.5 days, both with and without aeration. With aeration, the observed volumetric 2 TIS rate constant was averaged 5.7 day^{-1}; without aeration, the rate constant dropped to 0.52 day^{-1}. The results of these two studies indicate aerated wetland systems with a low energy input (approximately 10% of that required by an activated sludge process) can be used for ammonia removal, even at cold water temperatures.

KEYWORDS

Aeration, ammonia removal, cold climate, nitrification, vertical subsurface flow

INTRODUCTION

The standard design approach to constructed wetlands is to accept the wetland as a passive system that is constrained by internal mechanisms. As a result, large wetland areas are typically needed to address design challenges such as high mass loadings or low operating temperatures. In contrast, engineered wetlands are wetland reactors that are designed to allow some degree of process control over the system to improve treatment efficiency.

Engineered wetlands include aerated systems using direct aeration of the wetland bed (Wallace, 2001) or fill-and-drain strategies (Behrends *et al*., 1996; Sun *et al*., 1999). Similarly, wetlands that are designed with a reactive bed media that influences water chemistry can be considered engineered systems. Examples include medias that are designed to supply organic carbon (Kassenga *et al*., 2003), absorb phosphorus (Johansson, 1997; Drizo *et al*., 1997; Arias and Brix, 2004), or provide a specified cation exchange capacity (Johns *et al*., 1998; Gisvold *et al*., 2000).

This work focuses on the relative effects of temperature and oxygen availability in the removal of ammonia nitrogen. It can be demonstrated that relatively small energy inputs (in this case, injection of air from an air pump) can yield large increases in ammonia treatment efficiency. Data from two different pilot studies (Township of North Glengarry and Rosebel Gold Mine) are compared and contrasted.

METHODS

The pilot system at Alfred College consists of an aerated, vertical downward saturated subsurface flow wetland (1.08 m^2 surface area, 0.83 m bed depth, 1.3 cm gravel media) with supporting feed tanks and equipment. The system can be heated or refrigerated to control operating temperatures. The pilot facility is shown in Figure 1. Aeration is provided by a small compressor capable of delivering approximately 2×10^{-3} m^3/s per cubic meter of wetland bed. Testing of the aeration system is shown in Figure 2.

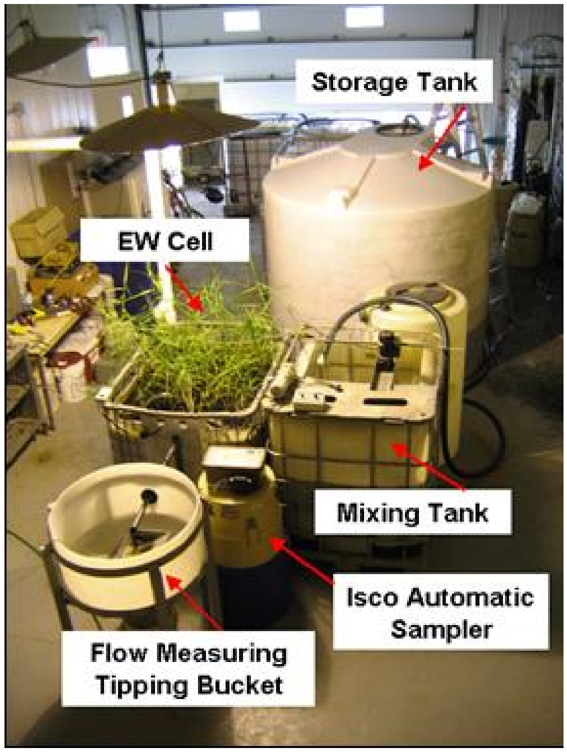

Figure 1. Engineered Wetland Pilot Facility at Alfred College, Canada.

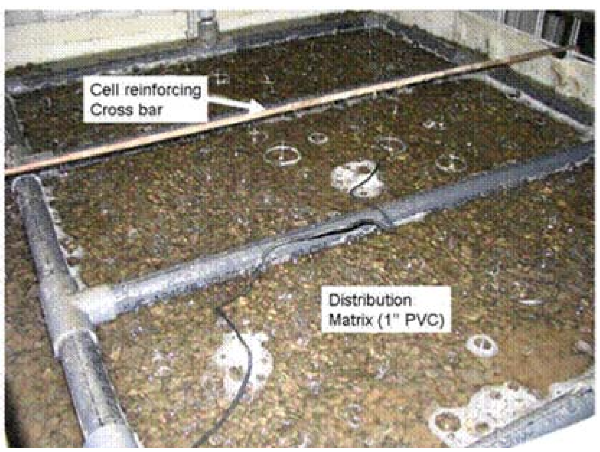

Figure 2. Testing of the Aeration System (note bubbles at water surface).

For each pilot study, ammonia grab samples were collected 5 times per week and analyzed using the colorimetric Phenate Method as outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1998).

Rosebel Gold Mine

For the Rosebel Gold Mine project, the pilot facility was operated to assess the ability of an engineered wetland to nitrify process water from a gold mining operation in Suriname, South America. For most phases of the pilot, a synthetic feed stock was used, but for one phase of operation (Run C) the pilot was operated with actual wastewater shipped from the job site. The pilot was operated with and without aeration. Operational phases are summarized in Table 1:

Table 1: Operational phases during the Rosebel Gold Mine Study

Run	A	B	C	D
Dates (2005)	15 Feb – 11 Mar	11 Mar – 18 Mar	23 Mar – 29 Mar	29 Mar – 6 Apr
Hydraulic Loading, cm/d	14.7	14.7	12.0	12.0
Feedstock	Synthetic	Synthetic	Actual	Synthetic
Aeration	On	Off	On	On
Temperature, °C	24.0	24.9	24.3	25.3

Township of North Glengarry

For the North Glengarry project, the pilot facility was operated to assess the ability of an engineered wetland to nitrify domestic wastewater from a municipality in Eastern Ontario. The pilot was operated in an aerated mode at two different temperatures using domestic wastewater from the town of North Glengarry. Operational phases are summarized in Table 2:

Table 2: Operational phases during the North Glengarry Study

Run	High Temperature	Low Temperature
Dates (2005)	13 May – 30 Jun	1 July – 16 Sep
Hydraulic Loading, cm/d	33.5	32.8
Feedstock	Actual	Actual
Aeration	On	On
Temperature, °C	25.2	6.0

RESULTS

During the Rosebel Gold Mine study, the wetland was tracer tested using sodium bromide and was observed to operate as one completely stirred tank reactor (CSTR) (as reported in Higgins *et al*., 2006). However, since this degree of internal mixing would likely not occur in a full-scale wetland system, results presented here are based on a two tank-in-series (2 TIS) model.

Township of North Glengarry

Based on observed ammonia nitrogen removal rates, rate constants for a 2 TIS hydraulic model were calculated as summarized in Table 3.

Table 3. Ammonia nitrogen removal rate constants for the North Glengarry pilot study

Run	A	B
Temperature, °C	25.2	6.0
k_t, 2 TIS (d^{-1})	10.0	8.4

Based on this data, the Arrhenius factor (θ) was calculated to be 1.02. This is in close agreement with the θ factor of 1.04 reported elsewhere in the literature (Kadlec and Knight, 1996). The 2 TIS ammonia nitrogen removal rate constant at 20°C (k_{20}) is 9.0 d^{-1}.

Rosebel Gold Mine

Rate constants for observed ammonia nitrogen removal were calculated for each of the four runs. Rate constants were temperature corrected to 20°C using a θ factor of 1.02 as calculated from the North Glengarry data set. Results are summarized in Table 4.

Table 4. Ammonia removal rate constants for the Rosebel Gold Mine pilot study

Run	Feedstock	Aeration	k_{20}, 2 TIS (d^{-1})
A	Synthetic	On	4.56
B	Synthetic	Off	0.52
C	Actual	On	5.54
D	Synthetic	On	7.02

On runs where aeration was employed (Runs A, C, D) the 2 TIS ammonia nitrogen removal rate constant averaged 5.7 d^{-1}. In contrast, without aeration (Run B), the rate constant dropped to 0.52 d^{-1}.

DISCUSSION

Data from the Rosebel Gold Mine study clearly demonstrates the effect of aeration on ammonia nitrogen removal. Without aeration, the 2 TIS rate constant observed in the pilot (0.52 d^{-1}) is similar to standard subsurface flow wetlands. By comparison, a standard area-based PFR rate constant of 34 m/yr (Kadlec and Knight, 1996) yields an equivalent 2 TIS volumetric constant of 0.36 d^{-1} for the pilot system, which is comparable to the non-aerated rate observed in Run B.

When aeration was employed, ammonia nitrogen removal rates were approximately 10-fold greater (5.7 d^{-1}) than without aeration (0.52 d^{-1}). This increase in ammonia nitrogen removal was observed both before (Run A) and after (Runs C and D) the non-aerated run. Enhanced ammonia nitrogen removal as a function of aeration has been previously presented for landfill leachate and manure runoff (Kinsley *et al*., 2002).

Low water temperatures (6°C) of the North Glengarry aerated wetland pilot did not impede treatment performance. Data from the North Glengarry pilot indicate that ammonia nitrogen removal rate constants are still considerably higher than in non-aerated wetlands, even at cold water temperatures. This information is consistent with a growing body of knowledge that cold-climate ammonia nitrogen removal is sustainable in aerated subsurface flow wetland systems (Nivala, 2005).

Since aerated wetlands have substantially higher ammonia nitrogen removal rates, reactor sizes are considerably smaller than for non-aerated wetlands. In the case of North Glengarry, a standard non-aerated subsurface flow wetland would be approximately 30.4 hectares; the engineered wetland alternative is only 1.4 hectares in size.

More efficient treatment through addition of an external energy input (in this case the injection of compressed air), can in some cases be justified due to smaller wetland areas and lower capital costs. While not entirely passive systems, these wetlands use considerably less energy than standard mechanical treatment processes. The full-scale North Glengarry wetlands have an external energy input of only 0.16 kWh/m^3. This energy input is considerably less than activated sludge processes, (2.39 – 0.51 kWh/m^3), and 'Living Machine' systems based on activated sludge principles (39 – 1.51 kWh/m^3) (Brix, 1999).

CONCLUSIONS

Data presented in this study indicate that ammonia nitrogen removal rates in aerated subsurface flow wetland systems are approximately 10 times higher than in non-aerated wetland systems, and that ammonia nitrogen removal can be sustained during cold water temperatures. Aerated wetland systems are both cost effective and energy efficient when compared to other wastewater treatment technologies.

REFERENCES

APHA (1998). *Standard Methods for the Examination of Water and Wastewater.* Clesceri, L.S., Greenberg, A.E., Eaton, A.D. (eds.), 20th edition, APHA, AWWA, WEF, Washington, DC.

Arias C.A., Brix H. (2004). *Phosphorus removal in constructed wetlands: Can suitable alternative media be identified?* Liénard, A., Burnett, H. (eds.). Proceedings of the 9th International Conference on Wetland Systems for Water Pollution Control, 26-30 September 2004; IWA Publishing: Avignon, France, pp. 655-661.

Behrends L., Sikora F., Coonrod H., Bailey E., Bulls M. (1996). *Reciprocating subsurface-flow constructed wetlands for removing ammonia, nitrate, and chemical oxygen demand: Potential for treating domestic, industrial, and agricultural wastewaters*. Proceedings of WEFTEC '96; the 69th Annual Conference and Exposition of the Water Environment Federation; Water Environment Federation: Alexandria, Virginia, United States.

Brix H. (1999). How 'green' are aquaculture, constructed wetlands and conventional wastewater treatment systems? *Water Science and Technology* **40**(3), 45-50.

Drizo A., Frost C.A., Smith K.A., Grace J. (1997). Phosphate and ammonium removal by constructed wetlands with horizontal subsurface flow, using shale as a substrate. *Water Science and Technology* **35**(5), 95-102.

Gisvold B., Odegaard H., Follesdal M. (2000). Enhanced Removal of Ammonium by Combined Nitrification/Adsorption in Expanded Clay Aggregate Filters. *Water Science and Technology* **41**(4-5), 409-416.

Higgins J.P., Liner M.O., Verkuijl S., Crolla A.M. (2006). *Engineered wetland pilot-scale treatability testing of ammonia- and cyanide-contaminated South American gold* *mine reclaim water (submitted)*. 31st Annual Meeting and Conference of the Canadian Land Reclamation Association (CLRA) and the 9th Meeting of the International Affiliation of Land Reclamationists, 20-23 August 2006; Ottawa, Ontario, Canada.

Johansson L. (1997). Use of LECA (Light Expanded Clay Aggregates) for the removal of phosphorus from wastewater. *Water Science and Technology* **35**(5), 87-94.

Johns M., Lesikar B.J., Kenimer A.L., Weaver R.W. (1998). *Nitrogen fate in a subsurface flow constructed wetland for on-site wastewater treatment*. Proceedings of the 8th National Symposium on Individual and Small Community Sewage Systems; American Society of Agricultural Engineers: Orlando, Florida, United States, pp. 237-246.

Kadlec R.H., Knight R.L. (1996). *Treatment Wetlands.* CRC Press, Boca Raton, Florida, United States.

Kassenga G., Pardue J.H., Blair S., Ferraro T. (2003). Treatment of chlorinated volatile organic compounds in upflow wetland mesocosms. *Ecological Engineering* **19** 305-323.

Kinsley C.B., Crolla A.M., Higgins J. (2002). *Ammonia reduction in aerated subsurface flow constructed wetlands*. Proceedings of the 8th International Conference on Wetland Systems for Water Pollution Control, 16-19 September 2002; Comprint International Limited: University of Dar Es Salaam, Tanzania, pp. 961-971.

Nivala J.A. (2005). Dissertation: Treatment of landfill leachate using an enhanced subsurface-flow constructed wetland. MS, Department of Civil and Environmental Engineering, University of Iowa.

Sun G., Gray K.R., Biddlestone A.J., Cooper D.J. (1999). Treatment of agricultural wastewater in a combined tidal flow: Downflow reed bed system. *Water Science and Technology* **40**(3), 139-146.

Wallace S.D. (2001). Patent: System for removing pollutants from water. Minnesota, United States 6,200,469 B1.