NITROGEN REMOVAL THROUGH THE USE OF RECIRCULATION AND CARBON MEDIA IN THE AQUA WETLAND SYSTEM

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ABSTRACT

Nitrogen removal was improved in the Aqua Wetland System through recirculation of the first cell effluent to a recirculation tank receiving septic tank effluent. Recirculation improved aeration within the first cell, lowering biochemical oxygen demand and increasing nitrification. Nitrate in the recirculated effluent was denitrified in the anoxic conditions in the recirculation tank, making use of the carbon contained in the septic tank effluent. For sanitary sewage treatment, recirculation resulted in total nitrogen levels of 8 mg/L. Subsequently, a third cell was introduced in a series of four cells which contained wood shavings or chips in saturated anoxic conditions. This measure brought total nitrogen down to 3 mg/L.

INTRODUCTION

The Aqua Wetland System (AWS) is a wetland design which uses intermittent pressure dosing and vertical sub-surface flow to maintain aerobic conditions to provide reliable year-round performance. The wetland is 1.2 m deep, with three or four cells, each with specific media, operated in series to achieve a high level of nitrogen removal. The first cell receives septic tank effluent and recirculates the wastewater through gravel media. The second to last cell contains organic media such as wood shavings which provide a slow-release carbon source for denitrification under saturated conditions. The final cell contains a medium grained sand to provide a final polishing and may also incorporate recirculation within the cell. The surface layers of all cells consist of a sand and peat mixture around the dosing pipes with a mulch and plant litter layer on the surface. Cells are generally planted with nursery grown cattails (Typha sp.) but may be planted with aesthetically desireable plant species, such as wildflowers from seed.

The AWS provides tertiary treatment for a wide variety of wastewater types, including septic tank effluent, landfill leachate, high strength winery process water, bakery process water, abattoir wastewater, compost leachate from mushroom farms, and greenhouse irrigation leachate. Over fifty wetland systems have been installed since 1998, over thirty operating under Ontario MOE Certificates of Approval, two approved by Health Canada for sanitary sewage on First Nations Reserves, several approved under the Ontario Building Code and two permitted by NDPES for landfill leachate in the United States. A Certificate of Approval is not required for the remaining systems because they are closed loop systems with no discharge to the environment. The smallest AWS treats 1,850 L/day of sanitary sewage at a cottage in northern Ontario and the largest treats 400,000 L/day of greenhouse irrigation leachate at a greenhouse in southern Ontario.

The initial once-through flow pattern of the AWS provided good removal of BOD and TSS to under 10 mg/L. Recirculation of cell 1 effluent was introduced partly to reduce the BOD in high strength industrial wastewater, e.g. winery wastewater, which could overload the sand media, but it was found that this also resulted in greatly improved nitrification and denitrification. Subsequently, the addition of carbon media to a saturated penultimate cell was introduced as a means of further reducing nitrogen.

Recirculation of cell 1 effluent enhances nitrogen removal by lowering the BOD to allow nitrifying bacteria to compete and by bringing nitrate back to the recirculation tank where anaerobic conditions and carbon in the wastewater provide conditions for denitrifying bacteria to convert nitrate to nitrogen gas. The recirculation rate is approximately 1-6 Q (daily design flow), depending on the size of the recirculation pump which is typically a 1/6 hp fountain pump running constantly. Some nitrogen will pass through to cell 3 where carbon is provided by wood shavings or chips and low oxygen conditions are maintained by saturating the bottom half of the cell.

METHODOLOGY

Grab samples were taken from the AWS effluent and shipped with ice in insulated containers for analysis of standard wastewater parameters at an MOE accredited laboratory.

The results compare data from three wetland designs:

1. three cell AWS with no recirculation;
2. same three cell AWS with recirculation of cell 1 effluent to a recirculation tank receiving septic tank effluent; and
3. four cell AWS with recirculation of cell 1 effluent and a partially saturated cell 3 containing wood chips.

Figure 1 is a schematic of the original and modified cell designs.

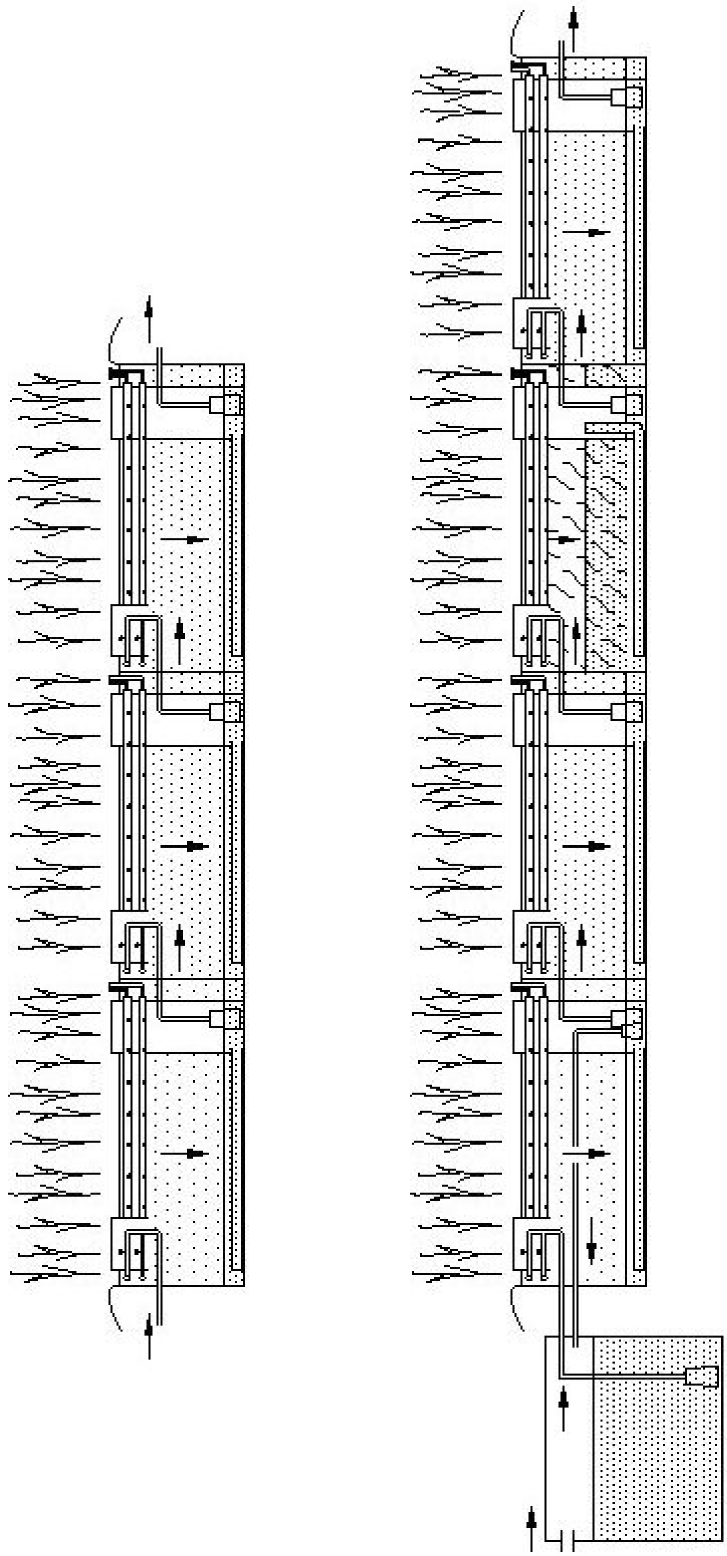

FIGURE 1: TOP: ORIGINAL THREE CELL CONFIGURATION. BOTTOM: MODIFIED CONFIGURATION WITH RECIRCULATION AND CARBON CELL.

RESULTS

Data are shown from a Niagara winery which generates sanitary wastewater from a restaurant and where the wetland cell 1 was modified for recirculation. Effluent from cell 1 is recirculated back to the flow balancing tank which receives septic tank effluent.

Ammonia and nitrate levels were variable and elevated previous to the onset of recirculation (September 2004), changing to uniformly low ammonia and nitrate concentrations after (see figure 2). Prior to using recirculation, nitrification was poor in the winter months (November 2003 to May 2004), but after recirculation nitrification was complete even during the winter. An effluent with 8 mg/L total nitrogen and almost complete nitrification was achieved.

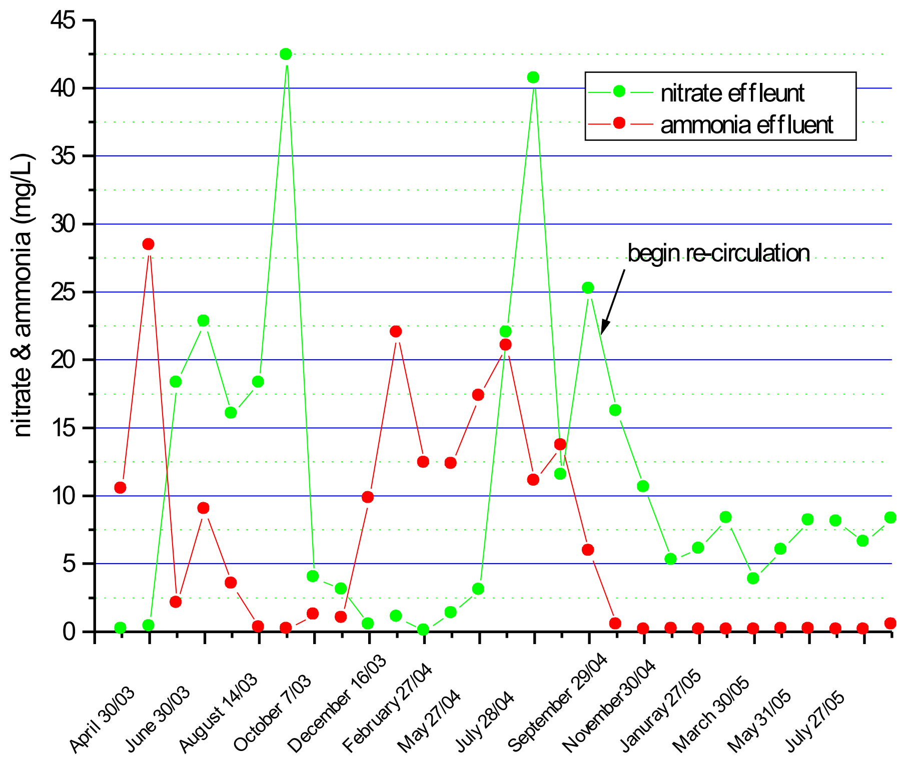

FIGURE 2: NITROGEN REMOVALS IN A NIAGARA WINERY BEFORE AND AFTER THE INTRODUCTION OF RECIRCULATION

Denitrification also occurs in the AWS cells, although the magnitude is only apparent by tracking the total nitrogen concentrations. The following table shows test results from a Niagara winery, comparing the winter previous and winter following the start of nitrification. In addition to completely nitrifying the ammonia, it can be seen that total nitrogen was reduced a further 60% by using recirculation around cell 1. In addition, BOD and TSS were reduced 62% and 60%, respectively, by recirculation.

TABLE 1: DATA FROM A NIAGARA WINERY BEFORE AND AFTER THE INTRODUCTION OF RECIRCULATION (IN mg/L)

Before recirculation							
Date	**BOD**	**TSS**	**TKN**	**ammonia**	**nitrate**	**nitrite**	**Total N**
Nov 19/03	3.0	2.0	1.7	1.0	3.1	0.1	4.7
Dec 16/03	16.0	7.0	11.4	9.8	0.5	0.1	11.9
Jan 31/04	16.0	9.0	25.8	22.0	1.1	0.1	26.9
Feb 27/04	10.0	4.0	16.4	12.4	0.1	0.1	16.5
Apr 29/04	6.0	2.0	13.0	12.3	1.3	0.1	14.3
May 27/04	9.0	8.0	18.9	17.3	3.1	1.2	23.2
Jun 29/04	4.0	3.0	23.2	21.0	22.0	1.3	46.5
Average	9.1	5.0	15.8	13.7	4.4	0.4	20.6
After recirculation							
Date	**BOD**	**TSS**	**TKN**	**ammonia**	**nitrate**	**nitrite**	**Total N**
Nov 30/04	3.0	2.0	0.5	0.1	10.6	0.0	11.1
Dec 29/04	2.0	2.0	1.3	0.2	5.2	0.1	6.6
Jan 27/05	2.0	2.0	0.5	0.1	6.1	0.1	6.6
Feb 28/05	5.0	2.0	0.5	0.1	8.3	0.1	8.9
Mar 30/05	3.0	2.0	1.1	0.1	3.8	0.1	5.0
Apr 27/05	3.0	2.0	0.9	0.2	6.0	0.1	7.0
May 31/05	5.0	2.0	2.1	0.2	8.1	0.1	10.3
Jun 23/05	5.0	2.0	2.0	0.1	8.1	0.1	10.1
Average	3.5	2.0	1.1	0.1	7.0	0.1	8.2

In order to provide further denitrification in subsequent designs, an additional cell was inserted before the last cell, with a 50/50 mixture of wood shavings and sand. Recirculation and a carbon medium resulted in nitrate levels of 3 mg/L or less in a sanitary sewage AWS trial (bakery employee sanitary AWS pilot).

Results from an AWS treating sanitary sewage from Valley View public school in Val Caron, near Sudbury Ontario, demonstrate a successful full-scale implementation of a system with recirculation tank, a carbon media cell 3, and recirculation within cell 4 for polishing (see table 2).

TABLE 2: DATA FROM VALLEY VIEW PUBLIC SCHOOL (IN mg/L EXCEPT *E. coli*)

Date	CBOD mg/L	BOD	TSS	TP	TKN	Amm.	Nitrate	E. coli cfu/100 ml
Oct 29, 07	1	3	2	0.03	1.5	0.7	1.9	2
Jan 31, 08	1	1	2	0.1	0.5	0.1	1.4	2

DISCUSSION

BOD reduction and denitrification provided by recirculation of AWS cell 1 effluent to the recirculation tank is the primary means of increasing nitrogen removal, reducing total nitrogen from approximately 20 to 8 mg/L. The saturated cell 3 is the secondary means of nitrogen removal and reduces total nitrogen from approximately 8 to 3 mg/L.

The carbon source in the recirculation tank is replenished through the septic tank effluent. The cell 3 carbon source in the form of wood shavings, in contrast, is a finite supply.

How long will the wood chips be effective? Taking Valley View public school as an example, cell 3 has an area of 90 m^2. The depth of media containing wood chips is 0.75 m. Assuming a void space of 40%, the volume of solid media is 41 m^3. Approximately half of this is sand and half is wood chips, so the solid volume of wood is 20 m^3 . The softwood has an approximate density of 500 kg/m^3 and a moisture content of 30%. The total dry weight of wood is 7,088 kg. Using the formula for cellulose of $C_6H_{10}O_5$, the wood is 44% carbon and the weight of carbon is 3,150 kg.

At a design flow of 24,300 L/d and a nitrate concentration of 8 mg/L entering cell 3, the weight of N as nitrate is 0.19 kg/d. Using a ratio of 5 carbons used to process 4 nitrogens for the reaction from nitrate to nitrogen gas (Wallace and Knight, 2006), the amount of carbon used up is 0.24 kg/d. At this rate it would take 35 years to use up 7,088 kg.

At 35 years expected replacement interval for the media in cell 3, this maintenance operation is consistent with the goal of longevity and simplicity in constructed wetlands.

The multiple cells in series approach of the AWS design has lent itself well to modifications to achieve high performance, compared to early single cell intermittent sand filters and constructed wetlands. The use of recirculation for denitrification is long-standing in municipal sewage treatment and the use of wood as a carbon source was demonstrated previously by researchers such as Will Robertson at the University of Waterloo. The AWS modification adapted these techniques successfully into constructed wetland approach.

CONCLUSIONS

Recirculation of cell 1 effluent to a recirculation tank containing septic tank effluent reduced BOD and TSS levels from below 10 to below 5 mg/L. Total nitrogen dropped from 20 mg/L to 8 mg/L. The introduction of wood chip carbon media to a cell 3 in a four cell series reduced total nitrogen from 8 mg/L to 3 mg/L. In keeping with the passive, low-maintenance nature of constructed wetlands, the carbon is expected to last on the order of 35 years before the cell media needs to be replaced.

REFERENCES

Wallace, S., R. Knight. 2006. "Small-scale Constructed Wetland Treatment Systems" Water Environment Research Foundation, Alexandria.