Removal of Nitrate by 'Anoxic Absorbent Filtration' and Carbon Addition

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Introduction

Nitrogen removal using a new technology suitable for smaller and isolated flows is being tested at commercial sites in Ontario. The 'WaterNOx' system is a variant of the 'post-anoxic' biological anoxic filtration (BAF) process with carbon source addition to nitrified effluent (e.g., Crites and Tchobanoglous, 1998). The system utilizes absorbent filter medium in asphyxiant, stagnant air conditions to form an 'anoxic absorbent filter' (AAF). This article describes the nitrification-denitrification system retrofitted into existing commercial sewage treatment systems (Figure 1), using three carbon sources and different loading rates, discusses observed alkalinity stoichiometry, and predicts results expected at various stages of the process.

Factory Site 1

At Site 1, a light industrial factory, three carbon sources were tried. Carbon 1, a monosaccharide carbohydrate, removed nitrate, but had plugging problems; Carbon 2, a disaccharide carbohydrate, was successful and easy to use; Carbon 3, an acetate, was successful though more expensive. Here, a Waterloo Biofilter nitrifies the 100-200 mg/L TKN sewage and the effluent used to test the 3.5 m^3 *AAF*. The AAF effluent is re-directed back through the nitrifying Waterloos to remove excess BOD from the carbon source.

Site 1 Results

The system was inoculated on April 9, 2008 and was mature within 10 days. Over the 12-week trial using Carbon 2 (Table 1), $NO_{2,3}$-N is reduced from 41 mg/L to <0.1 mg/L; alkalinity of 177 mg/L is increased to 289 mg/L, DO is reduced from >5 mg/L to <1 mg/L, and pH of 7.9 is lowered to 7.3 (not shown) between the inlet and outlet of the *AAF* (n = 11; medians). The excluded April 24 anomaly caused by tampering with control panels shows quick recovery after a disturbance.

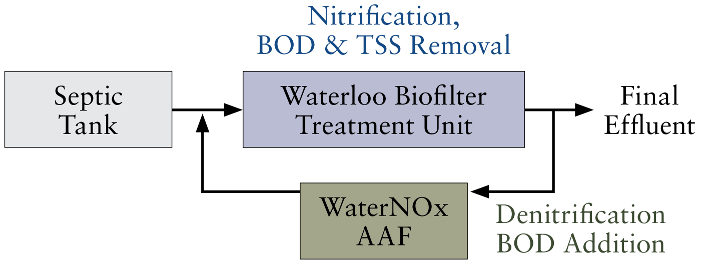
Fluctuating influent TKN values make carbon addition rates uncertain. The AAF effluent contains excess carbon (100-150 mg/L cBOD) and this was polished to <10 mg/L cBOD and <10 mg/L TSS in the final effluent.

With this test of 25-35% of the flow, nitrogen is reduced from 100-200 mg/L TN to ~50 mg/L TN in the final effluent, compared to >100 mg/L TN before the *AAF* was installed.

Truck Stop Site 2

Site 2 is a truck stop on Highway 401 near Cambridge ON with restaurant and gas bars. A distinctive component is a 'dead end tank' with off-site treatment for degreasers and disinfectants, making nitrification and denitrification easier (*Jowett et al., 2008*).

***Figure 1** – Process diagram of retrofitted test installations in this article. Nitrified final effluent is redirected to the AAF where it mixes with external carbon for denitrification.*



Site 2 Results

A 7 m^3 AAF filter was inserted to remove nitrate formed by existing Waterloo Biofilter nitrifiers. First using 3.1 L/d of Carbon 3 (Table 2), nitrate values plateaued at 10-15 mg/L and DO values were >1 mg/L in the AAF effluent. The cBOD and TSS were <10 mg/L, indicating that all of Carbon 3 was used up before complete denitrification was accomplished. Carbon 3 rate was increased to 3.4 L/d and nitrate dropped to <10 mg/L within 1 week (October 15) and to <5 mg/L within 2 weeks (October 21), with DO <1 mg/L. Effluent cBOD and TSS remained below 10 mg/L. Site 2 sewage TKN is stable compared to Site 1, and enables better estimation of the carbon source and flow rate combinations.

The November 26 anomaly of ~22 mg/L $NO_{2,3}$-N was caused by depletion of carbon supply, but within a week of carbon replenishing, the system returned to normal. However, the new Carbon 3 carboy caused an inexplicable cBOD increase from <10 mg/L to >100 mg/L, while TSS remained at <10 mg/L.

Efficiency comparison

The efficiency of nitrate removal is shown in Table 3. Density of undiluted Carbon 2 is 1.33 kg/L, and 50% diluted Carbon 3 is 1.27 kg/L or ~0.624 kg acetate per litre solution. Carbon 2 is more efficient than Carbon 3 per volume especially, but also by mass. At Site 1, Carbon 2 removes $0.105 \div 0.041 = 2.6$ times more nitrate per litre and costs half as much per litre as Carbon 3, or ~20% the cost per $NO_{2,3}$-N removed. Safety and operation considerations are similar for both carbon sources.

O&M Protocol

Low maintenance for isolated, rural flows was a prime design goal. The AAF medium is not back-washed, but cleaned of excess biomass with

***Table 1** – Site 1 Carbon 2 values of nitrified (IN) and denitrified (OUT) effluent*

	AAF Flow	Carbon 2	$NO_{2,3}$-N IN	$NO_{2,3}$-N OUT	Alkalinity IN	Alkalinity OUT	DO IN	DO OUT
2008	L/day	L/day	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Apr 17	3800	2.3	54	0	124	271	5.6	1.7
Apr 24	3800	2.3	62	59	177	128	5.3	7.8
Apr 30	3800	2.3	32	0	196	279	6.1	0.5
May 08	3800	2.0	27	0	202	286	5.7	1.3
May 12	3800	2.0	21	0	203	272	7.6	0.5
May 21	4650	2.0	49	0	145	334	6.0	0.5
May 30	4650	2.0	40	0	-	450	-	1.6
Jun 04	4650	2.0	34	0	467	376	6.0	2.3
Jun 10	4650	2.0	48	0	146	304	4.0	1.2
Jun 18	4650	2.0	42	0	183	319	5.0	0.8
Jun 25	4650	2.0	51	0	130	284	4.5	1.1
Jul 02	4650	2.0	38	0	160	292	4.6	1.3

***Table 2** – Site 2 Carbon 3 values of nitrified (IN) and denitrified (OUT) effluent*

**interpolated from weekly samples before and after*

	AAF Flow	Carbon 3	$NO_{2,3}$-N IN	$NO_{2,3}$-N OUT	Alkalinity IN	Alkalinity OUT	DO IN	DO OUT
2008-09	L/day	L/day	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sep 12	3000	3.1	37	21.5	348	586	5.2	2.7
Sep 17	3000	3.1	38	14.2	301	466	5.9	1.5
Sep 24	3000	3.1	46	12.1	329	731	4.9	1.6
Oct 01	3000	3.1	40	10.1	396	775	5.3	1.2
Oct 07	3000	3.1	40	12.6	397	666	5.8	1.3
Oct 15	3000	3.4	39	7.2	389	835	5.5	0.9
Oct 21	3000	3.4	37	4.4	382	817	5.6	1.0
Oct 29	3000	3.4	29	2.2	417	829	6.9	0.8
Nov 04	3000	3.4	30	0.1	-	792	6.0	0.0
Nov 13	3000	3.4	20	0.1	279	693	6.4	0.0
Nov 19	3000	3.4	25	0.1	320	714	-	1.0
Nov 26	3000	3.4	26	22	330	272	-	0.6
Dec 03	3000	3.4	21	0.1	210	740	-	-
Dec 10	3000	3.4	29*	0.1	320*	970	-	0.4
Dec 22	3000	3.4	35*	0.1	455*	1060	-	0.0
Jan 13	3000	3.4	29	0.1	480	1040	-	0.1

***Table 3** – Nitrate removal using different carbon sources. $NO_{2,3}$-N refers to removal of nitrate-N + nitrite-N between inlet and outlet of AAF.*

WATERNOx AAF Test Site	$NO_{2,3}$-N mg/L	Flow L/d	$NO_{2,3}$-N kg/d	Carbon volume L/d	Carbon mass kg/d	$NO_{2,3}$-N per carbon volume kg/L	$NO_{2,3}$-N per carbon mass kg/kg
Site 1 Carbon 2	45	4650	0.209	2.0	2.66	0.105	0.079
Site 1 Carbon 3	37	3060	0.113	2.75	1.72	0.041	0.066
Site 2 Carbon 3	26	3000	0.078	3.4	2.12	0.023	0.037

***Table 4** – Expected values for process components based on field trials of existing commercial facilities and dentrification results of the conventional and AAF processes.*

Works Effluent	cBOD	TSS	NH_4-N	NO_3-N
Facility	500-800	300-400	80-140	-
Septic Tank	250-400	150-200	80-140	-
Waterloo Biofilter	15	15	<5	40-80
'WaterNOx' AAF	75-100	10-40	<5	0
WATERLOO Polisher	15	15	0	<5

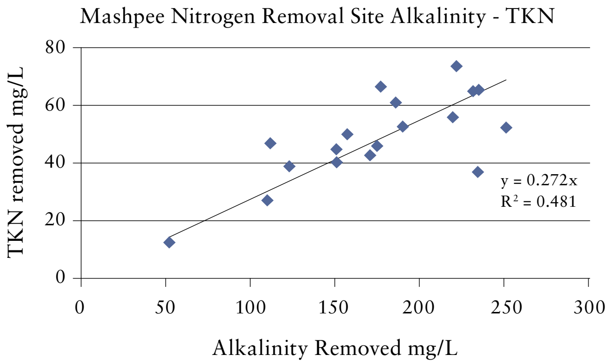


Figure 2 – Overall alkalinity balance during nitrification (alkalinity consumed) and denitrification by recirculation (alkalinity produced). Trend line is forced to zero.

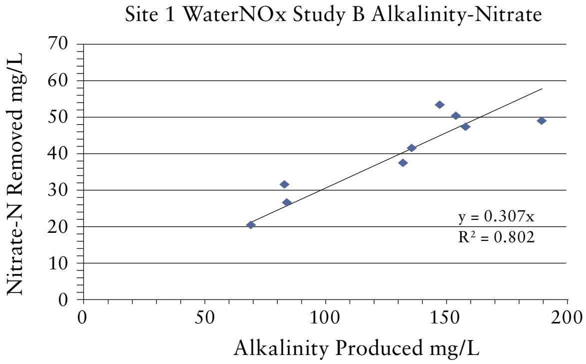


Figure 3 – Site 1 Carbon 2, alkalinity is produced in the AAF at ~3.3 mg/L per mg/L nitrate-N consumed, a stoichiometric relationship. Trend line is forced to zero.

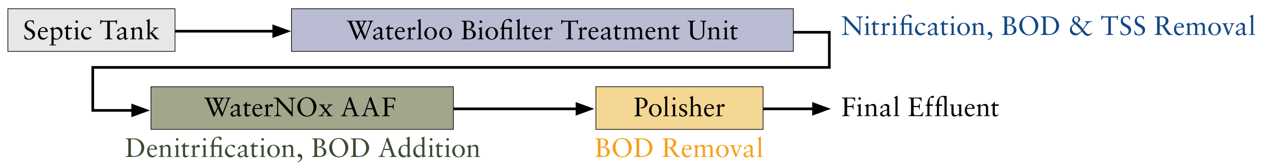


Figure 4 – Process diagram of the AAF denitrification system in a new installation, with a polisher added to remove excess BOD from the external carbon source.

microbial additives and by reducing the carbon input for a few days every 3-6 months. The carbon line and forcemain are ‘pigged’ out every 3-6 months to maintain clear flow.

Alkalinity Budget

Stoichiometric Septic Tank Carbon

Alkalinity is an important performance indicator in the *AAF* process. In a Massachusetts communal system without an AAF, 65% of TN is removed to ~18 mg/L TN with a Waterloo Biofilter and 50% recirculation to septic tank as internal carbon source (CWI, 2009). From the slope of the curve in Figure 2, ~3.7 mg/L alkalinity is consumed for each mg/L TKN nitrified in this ‘pre-anoxic’ process. Stoichiometrically, 7.14 mg/L alkalinity is consumed for each mg/L of TKN nitrified in a single-pass system (e.g., *Tchobanoglous et al., 2003*; p. 619). This site has full nitrification with very low alkalinity left, so it appears that denitrification in the septic tank produces ~3.5 mg/L alkalinity $(1 \div 0.272 - 7.14 \approx 3.5)$, making up the deficiency in alkalinity and helping overall nitrification.

Stoichiometric Carbon 2

From the slope of the curve in Figure 3 for single-pass denitrification between influent and effluent of the WaterNOx with external carbon addition, alkalinity is produced at ~3.3 mg/L per mg/L nitrate-N removed, similar to that assumed for the non-AAF site in Figure 2, and similar to the stoichiometric value of 3.57 mg/L for denitrification reactions (Tchobanoglous et al., 2003; p. 618). In the retrofitted cases such as in this article, this additional alkalinity is directed upstream to improve nitrification efficiency.

Non-Stoichiometric Carbon 3 at Sites 1 & 2

With Carbon 3, alkalinity is produced in the AAF at ~14 mg/L and ~71 mg/L for each mg/L nitrate-N consumed, in excess of that predicted from stoichiometry. This relationship is not explained, but it may be that the excess acetate masks the end point of the laboratory titration, as suggested by *Devlin (1990)* for landfill leachate.

Treatment Expectations

A full AAF design consists of nitrifier, denitrifier, and polisher in a treatment train, the latter two each half the size of the nitrifier (Figure 4). Polishing removes excess carbon, but also nitrifies excess TKN, so it is important to have enough alkalinity and healthy sewage for thorough nitrification.

Table 4 (page 39) shows projected values in the train, ultimately reaching <5 mg/L $NO_{2,3}$-N with the right design.

References

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