A Comparison of Operating Issues and Dosing Requirements for Alternative Carbon Sources in Denitrification Filters

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ABSTRACT

The need for alternative supplemental carbon sources to support denitrification has been magnified during the past few years because of parallel nutrient reduction initiatives for the Chesapeake Bay and Long Island Sound. As a result, research into the use of alternative carbon sources is ongoing, including investigation into the impacts of different substrates on activated sludge denitrification kinetics as well as establishing the carbon requirements specific to each substrate. Denitrification filters are a popular add-on technology for meeting low nitrogen limits, and test results from several facilities suggest that there are some unique operating considerations associated with the use of different carbon sources. This paper presents denitrification filter data for several alternative carbon sources, and compares and contrasts the performance with methanol and theoretical values.

KEYWORDS

Alternative Carbon Sources, Denitrification Filters, Methanol, Ethanol, Acetic Acid, MicroC^{TM}

INTRODUCTION

Denitrification filters have been used to meet stringent total nitrogen limits for over 30 years. Virtually every facility has historically used methanol as the readily biodegradable carbon source for denitrification. As a result of parallel nutrient reduction initiatives for several major watersheds, there has been a great deal of interest in alternative carbon sources because of the safety concerns associated with methanol, increases in methanol costs, and lapses in its availability. There is significant ongoing research into the denitrification kinetics, biomass yields, and operating issues associated with these carbon sources. Most of this research has been geared toward activated sludge systems, but some information has been compiled for denitrification filters as well.

How Much Chemical Is Needed?

Numerous studies have been conducted over the years to examine denitrification kinetics, carbon requirements, and cell yields associated with alternative carbon sources. McCarty *et al* (1969) studied the effects of a number of substrates on denitrification and reported substrate requirements for a number of carbon sources. Both the chemical quantity required to meet denitrification goals and the resulting sludge production are related to the cell yield, or the efficiency of the bacteria in converting COD into biomass. Of the substrate (or COD) consumed, some is converted into biomass and the rest is oxidized to carbon dioxide and water. Substrates with high yields result in higher sludge production. The kg of COD required to reduce one kg of nitrate-N is equivalent to 2.86 / (1-Yield). For denitrification, substrates with lower yields result in lower sludge production and lower COD requirements overall. The biomass yields and COD requirements for denitrification are listed for several common substrates in Table 1. As new supplemental carbon sources are introduced to the wastewater industry, additional research is needed to quantify substrate requirements and sludge yields to fully compare the effectiveness of different substrates.

Table 1. Selected Denitrification Kinetic and Stoichiometric Coefficients for Alternative Carbon Sources

Carbon Source	Maximum Specific Denitrifier Growth Rate		Yield, Y (g biomass COD/g substrate COD)	COD/NO$_3$-N Ratio
	m_{max}, 1/d	Temp, ^{o}C		
Methanol[a]	0.5	13	0.38	4.6
	1.0	19		
Methanol[b]	1.3	20 (developed Arrhenius coefficient of 1.13)		
Methanol[d]	0.52	10		
	1.86	20		
Methanol[e]	1.25	20 (developed Arrhenius coefficient of 1.13)	0.4	4.79
Methanol[f]			0.45	5.2 (calculated)
Acetate[a]	1.3	13	0.18	3.5
	3.7	19		
Acetate[b]	4.0	20		
Acetate[c]			0.192	3.6
Acetate[f]			0.18	3.5 (calculated)
Ethanol[a]	1.2	13	0.39	4.7
	3.5	19		
Ethanol[b]	1.3	20		
Ethanol[f]			0.51	5.9 (calculated)
Sugar[b]	4.0	20		
Sugar[f]			0.35	4.5 (calculated)
Glucose[c]			0.365	4.5
MicroC™[g]	3.66	20	0.55	6.45
	1.22	10	(calculated)	

References:
  (a) Mokhayeri, et al, 2006.
  (b) Dold et al, 2007.
  (c) Copp and Dold, 1998.
  (d) Tchobanoglous, Burton and Stensel, 2003.
  (e) Nichols, et al, 2007.
  (f) Adapted from McCarty, 1969.
  (g) Cherchi, et al, 2008.

TESTING RESULTS WITH DIFFERENT SUBSTRATES

There are several differences in operation between denitrifying activated sludge systems and tertiary denitrification filters. First, the filters are at the end of the process, and the carbon source must have a high level of control to avoid elevated BOD concentrations in the effluent. Also, a denitrification filter usually has fewer variables than an activated sludge process because

relatively clean wastewater is fed to the process. Finally, the impact of growth rate kinetics is slightly different from that of activated sludge because the bacteria attach to the media preventing washout. Case studies documenting operation with four different carbon sources – methanol, acetic acid, MicroC^{TM} and ethanol are presented in the following sections.

Methanol

Methanol has been used as a supplemental substrate for denitrification filters for over 30 years with excellent results. Methanol consumption in the range of 3 to 3.5 g methanol/g NOx-N removed (4.5 to 5.3 g COD/g NOx-N removed) has been documented at a number of facilities, including Tampa, FL and Scituate, MA, and these dosage ratios compare well with literature values.

Methanol consumption was rigorously monitored as part of the facilities acceptance testing at the Lower Reedy Wastewater Treatment Plant in Simpsonville, SC, which is owned and operated by the Western Carolina Regional Sewer Authority. Deep-bed denitrification filters were installed as a part of the recent expansion project to reduce the effluent total suspended solids before UV disinfection and to provide the capability for denitrification, should more stringent total nitrogen discharge limits be imposed in the future. During commissioning, a stringent performance test was conducted to demonstrate the capability of the filters to meet the required effluent nitrate-nitrogen + nitrite-nitrogen (NO_2-N + NO_3-N, or NOx-N) concentrations without using an excess of methanol.

The performance test was conducted during the winter to prove that the filters could provide the required treatment under cold weather operating conditions. After approximately six weeks of preliminary operation to establish the biomass, the test was conducted over a week-long period. Because there was no permanent methanol feed system at the Lower Reedy WWTP, a temporary system was supplied. Additionally, the filter influent wastewater was supplemented with sodium nitrate to simulate the design NOx-N loading.

The performance specifications for the filters included a penalty for exceeding the allowable methanol dosage, and the methanol consumption during testing was therefore monitored very closely. The allowable methanol consumption was based on the relationship developed by McCarty et al (1969) applied to actual conditions during testing:
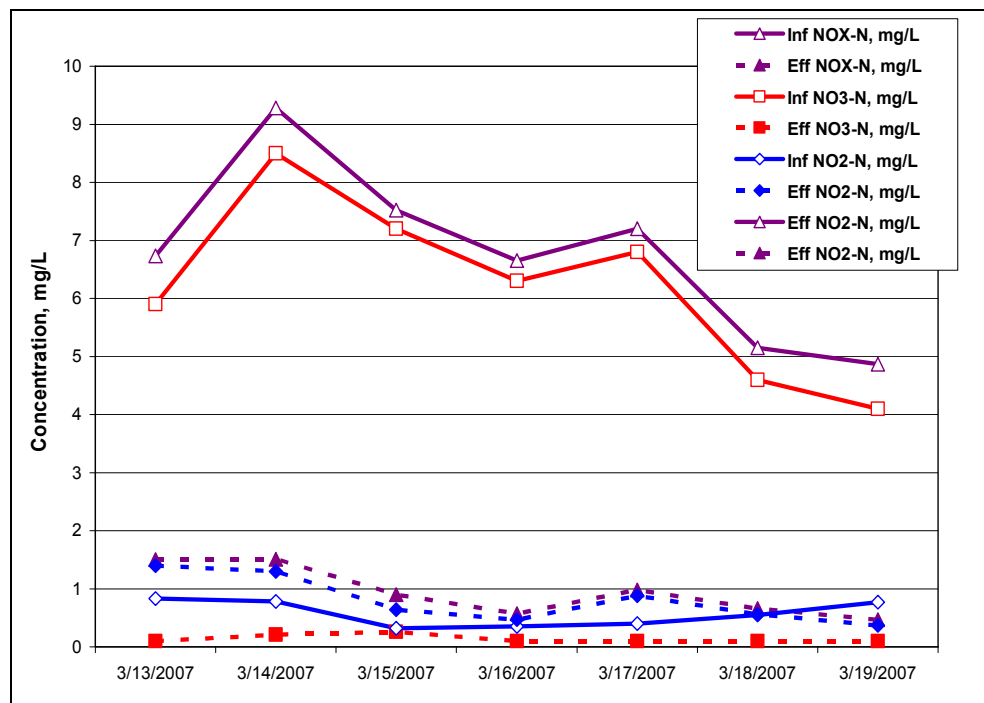
Methanol Requirement = (2.47 x NO_3-N removed) + (1.53 x NO_2-N removed) + (0.87 x DO Removed)

As long as the actual methanol consumption did not exceed the calculated requirement by more than 10%, the test was considered successful. In addition, the allowable effluent BOD concentration was fairly low at 5 mg/L. The filter design and performance requirements are summarized in Table 2.

Table 2. Lower Reedy Deep-bed Filters Design Criteria

Criterion	Average Design	Peak Design
Flow, m^3/d (mgd)	37,854 (10)	94,635 (25)
Influent NOx-N, mg/L	9	3.5
Effluent NOx-N, mg/L	<1	<1
Effluent BOD, mg/L	<5	
Effluent TSS, mg/L	<5	
Number of filters	6	
Area per filter, m^2 (ft^2)	54 (583)	

The filter influent and effluent NO_3-N, NO_2-N and NOx-N results are shown in Figure 1. The effluent NOx-N results met the performance requirement of lower than 1 mg/L NOx-N on average. It is noted during testing that NO_2-N concentrations entering the filter were slightly higher (0.3 to 0.85 mg/L) than typical secondary effluent NO_2-N concentrations of close to zero.

Figure 1. Lower Reedy WWTP Denitrification Filter Testing, Nitrate, Nitrite and NOx-N Removal Through the Filters

Methanol consumption was recorded daily. The allowable methanol consumption with the 10% safety factor was calculated using the actual nitrate, nitrite, DO, and flow values recorded during testing. The allowable and observed methanol consumption values are shown in Figure 2 as a ratio of methanol dosed to NOx-N removed. This corresponds to an average dosage of 3.53 g methanol/g NOx-N removed, or 5.3 g COD/g NOx-N removed.
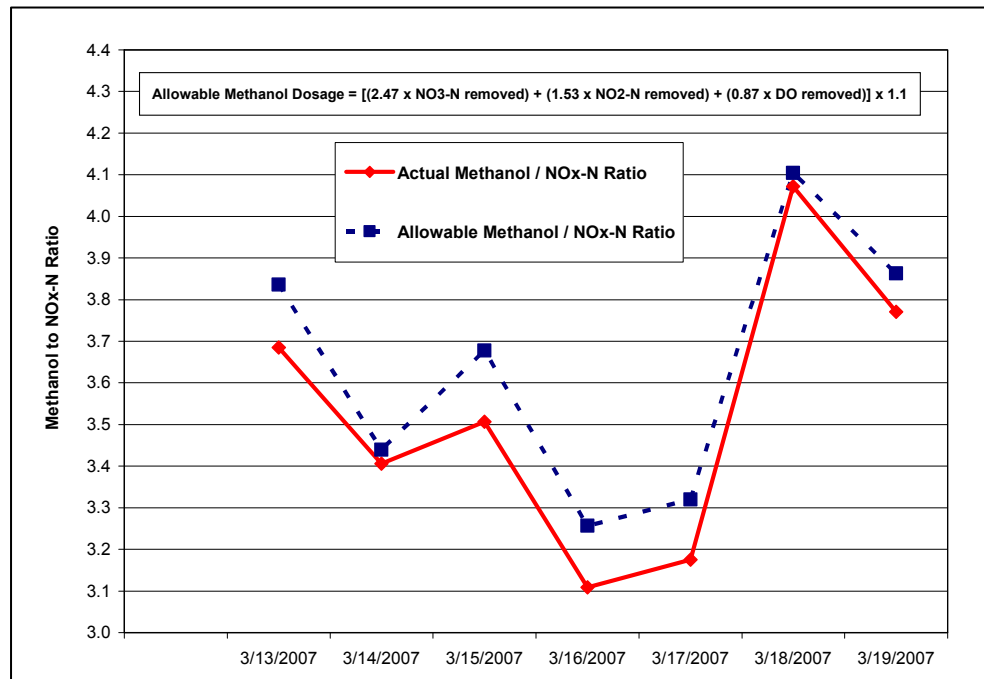
Figure 2. Lower Reedy WWTP Denitrification Filter Testing, Actual vs. Allowable Methanol Dosage Ratio

It is noted that these dosing ratios are on the high end of what is reported in literature. However, it is also noted that the DO concentrations in the filter influent (as measured in the filter, at the top of the media) averaged 5 mg/L. During testing, the influent NOx-N concentration trended downward, but the DO concentration remained fairly high throughout (some variation is observed as the filter liquid levels increased before backwashing). At the lower influent NOx-N concentrations of about 5 mg/L, the DO had a significant impact on the methanol/NOx-N dosing ratio. Filter influent and effluent BOD, total organic carbon (TOC), and chemical oxygen demand (COD) values show that the methanol dosages did not result in elevated carbon concentrations in the filter effluent (Table 3).

Table 3. Lower Reedy Filter Influent and Effluent CBOD, COD, TOC and DO Concentrations

Date	Influent CBOD[1], mg/L	Effluent CBOD, mg/L	Influent COD[1], mg/L	Effluent COD, mg/L	Influent TOC[1], mg/L	Effluent TOC, mg/L	DO in Filter at Top of Media
3/13/2007	6.6	4.1	34.6	27.4	12.7	11.7	5.5
3/14/2007	6.3	4.1	43.8	39.2	15.3	13.9	5.3
3/15/2007	5.1	3.8	51.1	48.8	18.1	17.0	6.3
3/16/2007	7.0	5.0	52.8	50.4	17.5	16.7	3.3
3/17/2007	4.0	8.0	44.8	53.1	16.1	15.7	3.4
3/18/2007	8.0	9.0	40.2	35.6	15.2	16.3	6.5
3/19/07	7.5	2.9	53.7	48.5	13.4	13.7	5.7
Average	6.4	5.3	45.9	43.3	15.5	15.0	5.1

Note:
(1) Filter influent samples were taken upstream from methanol addition.

In summary, observed methanol requirements closely matched the expected requirement and therefore compare relatively well with literature values. At lower NOx-N loadings and high influent DO concentrations, the methanol dosing when reported as a net COD/NOx-N removed ratio, increases significantly.

Acetic Acid

The McDowell Creek WWTP in Charlotte, NC was upgraded in 1998 from a two-stage plant for BOD removal and nitrification to a single stage activated sludge BNR process followed by denitrification filters. Sampling results during the design phase indicated that there was little VFA in the plant influent wastewater and a supplemental VFA source would be needed for the biological phosphorus removal process. In addition, a clean carbon source such as methanol was needed for the denitrification filters. After a review of suitable sources of supplemental carbon, it was decided to use a 20% waste acetic acid solution from acetaminophen manufacture as a source of both VFA for biological phosphorus removal and carbon for the denitrification filters. It is believed that this was the first full-scale denitrification filter installation designed and tested with acetic acid as the carbon source.

The filter complex consisted of four 46.8 m^2 (503.5 ft^2) cells, which were commissioned in May 1998. As an initial test, the filters were dosed with acetic acid in March; the required biomass developed quickly and good denitrification was observed within three days. Typical wastewater temperatures during March are 15 ^{o}C. Once the planning was completed, acetic acid feed was re-initiated on May 11, 1998. Again, significant denitrification was observed within three days, and filter performance was closely monitored from May 14 through 22. Filter influent and effluent NOx-N concentrations are shown in Table 4.

Table 4. McDowell Creek WWTP Performance Data Using Acetic Acid

Date	Flow, mgd	NOx-N in, mg/L	NOx-N out, mg/L	COD in, mg/L	COD out, mg/L	CBOD out, mg/L	TSS out, mg/L
5/141998	N/A	11	4	76	32	3.0	1.6
5/15/2008	N/A	11	N/A	83	26	3.2	3.1
5/18/1998	3.75	9	1.4	64	26	7.6	4.7
5/19/1998	3.40	10	1.3	79	<25	3.7	2.6
5/20/1998	3.23	10	1.3	75	32	2.4	1.9
5/21/1998	3.13	10	1.5	81	34	2.3	2.0
5/22/1998	3.25	10	1.1	81	35	3.1	2.2

Throughout testing, the average consumption of 20% acetic acid solution was 2,950 L/d (780 gal/d). At a solution density of 1.01 kg/L (8.459 lb/gal), this corresponds to an average dosage of 600 kg/d (1320 lb/d) as acetic acid, or 639 kg/d (1408 lb/d) as COD. As a ratio of COD/NOx-N, this works out to 5.94 g COD/g NOx-N removed. During testing, COD analyses were performed on composite samples of the filter influent and effluent wastewater. If the acetic acid consumption is calculated based on COD removal in the filters, this works out to 5.38 g COD/g NOx-N removed. It is noted that any TSS removal across the filters would contribute to the net COD removed. TSS data were not available for the filter influent, but are typically less than 5 mg/L in the McDowell secondary effluent and therefore should have had only a marginal impact on the net COD removed.

The literature suggests that the COD requirement for denitrification using acetic acid is on the order of 3.5 g COD/g NO_3-N removed (McCarty, 1969; Copp and Dold, 1998; Mokhayeri et al, 2006) which is significantly lower than the calculated acetic acid dosing rates of 5.38 and 5.94 g COD/g NOx-N removed. The higher use of acetic acid does not appear to be related to excess dosing because the effluent CBOD concentrations throughout the testing period averaged less than 4 mg/L. Effluent COD values during testing were a little higher than the historical effluent COD values of about 20 mg/L. This does suggest that perhaps some unused COD was carried through to the effluent (though it is noted that the COD/NOx-N ratio using the COD data is calculated by difference and therefore excludes COD in the effluent).

Dissolved oxygen measurements were not recorded at the time of testing. However, subsequent sampling has revealed that the DO entering the filters is quite high at 5 to 6 mg/L. This varies depending on the liquid level in the filters and the corresponding free-fall from the influent weir into the filters. Considering the low COD requirement for denitrification using acetic acid along with the high DO into the filters and higher aerobic biomass yields, it is possible that a larger proportion of the acetic acid dose is needed for reducing the DO than one might expect.

Another consideration is that the McDowell plant includes a biological phosphorus removal process which has glycogen accumulating organisms (GAOs). The GAO population was confirmed through several microbiological analyses of the mixed liquor at different times of the year during 2003, 2004, and early 2005. Although there is no confirmation of the presence of GAOs at the time the denitrification filter testing took place, it is likely they were there. It is

possible that, similar to what occurs in the activated sludge process, GAOs may be taking up acetate, making it unavailable for use in denitrification and thereby increasing chemical requirements..

MicroC^{TM}

The Scituate WWTP is located in Scituate, MA and has a design flow of 6,057 m³/d (1.6 mgd). After several years of operation using methanol at typical dosage ratios, the denitrification filters were tested in 2005 using MicroC^{TM}. This testing was a collaborative effort between the Scituate WWTP, Severn Trent Water Purification, Inc., and Environmental Operating Solutions, and was conducted to evaluate alternatives to methanol as the readily biodegradable carbon source for denitrification. MicroC^{TM} is a proprietary mixture of agriculturally derived compounds and 5.5% methanol, which lowers the freezing point and reduces the viscosity of the solution. Some of the testing results were reported by Firmin and Rowland (2007) and by Ledwell (2006).

The testing with MicroC^{TM} was conducted from September 6 through November 28, 2005. Four phases of operation were evaluated as follows:

- Pre-pilot Phase: January 1 through September 5 was spent on baseline data collection using methanol as the sole carbon source in the denitrification filters.
- Pilot Phase 1: September 6 through October 5 served as a transition period from methanol to MicroC^{TM}
- Pilot Phase 2: October 5 to November 28 consisted of operation using MicroC^{TM} as the sole carbon source in the filters.
- Post-pilot Phase: MicroC^{TM} dosing was discontinued on November 28 and methanol dosing was reinstated. Data for November 28 through December 18 were evaluated to assess the results of the transition from MicroC^{TM} back to methanol.

Although some variation was observed, depending on the testing phase, denitrification performance was very good, with filter effluent NO_3-N values averaging below 1 mg/L for the duration. Average flows and NO_3-N removal performance are summarized in Table 5.

Table 5. Summary of Filter Nitrate Removal Performance

Testing Period	Effluent Flow, mgd	Flow to Filters, mgd	Filter Effluent NO$_3$-N, mg/L	Filter Influent NO$_3$-N, lbs/d	Filter Effluent NO$_3$-N, lbs/d	NO$_3$-N Removed, lbs/d
Pre-pilot[1]	1.47	1.47	0.43	123.6	5.4	118.2
Phase 1	1.07	1.07	0.44	122.1	4.0	118.2
Phase 2[2]	2.05	1.76	0.80	127.3	11.2	116.1
Pilot Average	1.69	1.51	0.67	125.4	8.6	116.9
Post-pilot[3]	2.04	2.04	0.46	140.1	6.9	130.0

Notes:
  (1) January 1 to September 5, 2005
  (2) Phase 2 included several high flow events that resulted in some flow being bypassed around the filters. Phase 2 calculations were adjusted to reflect filter performance and exclude the bypassed flow.
  (3) November 28 through December 18, 2005						

During the pre-pilot phase from January 1 to September 5, 2005, the average methanol usage was 216 L/d (57gal/d). During this period, the average NO$_3$-N removal observed was 9.64 mg/L or 53.7 kg/d (118.2 lb/d). This corresponds to a methanol dosing ratio of 3.18 g methanol/ g NO$_3$-N removed or 4.8 g COD/g NO$_3$-N removed. These dosage requirements compare well with the literature and are lower than the dosing ratios presented earlier for the Lower Reedy WWTP (this is likely the result of higher nitrate values affecting the net dosage ratio in a more favorable manner than in the Lower Reedy case).

During Phase 2 of the pilot study, the MicroC^{TM} use was 550 L/d (145.4 gal/d). Since a portion of the peak flow was bypassed around the filter, a corresponding amount of MicroC^{TM} also was bypassed and the actual MicroC^{TM} dosage to the filters was 500 L/d (132.2 gal/d). At a solution density of 1.16 kg/L (9.67 lb/gal), and an NO$_3$-N removal of 52.7 kg/d (116.1 lb/d), this corresponds to 11 g MicroC^{TM} /g NO$_3$-N. MicroC^{TM} has a COD concentration of 670,000 mg/L and the resulting dosage ratio is equivalent to 6.36 g COD/ g NO$_3$-N removed. This is slightly higher than approximately 6 g COD/g NOx-N removed for denitrification in an activated sludge BNR system at the Parkway WWTP in Maryland (Wimmer et al, 2007) but the overall dosage is influenced by the very high DO concentrations entering the filters (average DO was 6.74 mg/L during testing). Additional research into dosage requirements for denitrification using MicroC^{TM} is being conducted at Northeastern University.

During operation with MicroC^{TM} a significant amount of white biological growth was observed to be rapidly developing on the filter influent launders and walls. Filter cells were backwashed

once every four days, and although the walls were cleaned immediately before each backwashing cycle, the biological growth would promptly begin to accumulate again as shown in Figure 3.

Filter Influent Weir After Cleaning   Biological Growth at Weir

Figure 3. Biological Growth on Filter Weirs

It was also noted that solids quantities in the backwash increased during operation with MicroC[TM], with VSS concentrations approximately 60% higher than those observed when using methanol. These backwash solids also included the contribution from the biological growth at the influent launder which was cleaned off the walls just before each backwash and was then removed from the filters during the backwashing cycle. The buildup of solids at the launder appeared to be causing some differences in flow distribution between filters which ultimately could impact their performance. The release of gas bubbles during bumping (nitrogen release cycles) appeared less intense and of a longer duration with MicroC[TM] than with methanol.

One of the goals of testing was to examine the transition from methanol to MicroC[TM] during Phase 1 and then from MicroC[TM] to methanol in the post-pilot phase. The transition from methanol to MicroC[TM] was made gradually over an entire month. Good performance was maintained throughout this transition period, with effluent NO_3-N concentrations averaging 0.44 mg/L. The transition back to methanol was made quickly and illustrated the impact of a more sudden change in the carbon source. MicroC[TM] dosing was discontinued on November 28 and methanol was reinstated. For the first four hours of operation with methanol, a minor decline in performance was observed, with the effluent NO_3-N concentration in the range of 1.5 to 2.5 mg/L. However, performance improved rapidly and effluent quality was restored to nitrate concentrations of less than 0.5 mg/L. MicroC[TM] solution includes 5.5% methanol, which appears to have been adequate for maintaining a significant population of methylotrophic bacteria throughout testing.

In summary, MicroC[TM] was an effective carbon source for denitrification but had the disadvantage of promoting excessive biological growth on the filter influent launders and walls.

In addition, similar to the observations with the use of acetic acid at the McDowell plant, the COD/NOx-N requirement was higher than anticipated. It is postulated that the more complex carbon sources are used by a broader bacterial community and may be more likely than methanol to promote undesired biological growth between the dosage location and the filter media than methanol. In addition, the high DO concentrations are likely to have a significant impact on the overall dosage.

Ethanol

Dravo Corporation conducted pilot testing to demonstrate the feasibility of denitrification filters for treatment of a waste stream high in nitrates. As discussed by Chen and Savage (1976), the pilot unit consisted of a series of two denitrification columns with a 5-ft effective media depth, designed for a test flow of 18,930 L/d (5,000 gal/d). Several phases of testing were run using various ethanol to NO_3-N dosing ratios to determine the effective NO_3-N removal that could be achieved without significant breakthrough of ethanol (and the corresponding increase in COD and BOD) in the effluent.

The NO_3-N concentrations in the pilot influent wastewater varied from 200 to 900 mg/L. The results showed that an ethanol to NO_3-N dosage ratio of 2.5 resulted in about 90% removal efficiency through the filters. This ratio corresponds to a COD to NO_3-N ratio of 5.2 which is lower than the COD/NO_3-N of 5.88 calculated from the consumptive ratio reported by McCarty (1969). Although specific information on the filter influent DO is not included, it is noted that the impact of any DO on the overall dosing ratio must have been minor at these uniquely high influent NO_3-N concentrations.

Backwash water samples were collected during testing to quantify the solids production rate and showed that the net solids production was 1.16 g TSS / g NO_3-N denitrified. The TSS concentrations in the filter influent and effluent wastewater were generally very similar and fairly low, averaging less than 10 mg/L. The backwash solids quantity corresponded to a TSS to COD ratio of 0.223. If most of the solids were VSS, and assuming a COD/VSS ratio of 1.42, the net yield would have been approximately 0.32 g biomass COD/g COD consumed. Specific information on VSS production is not available and this net yield was affected by biomass decay in the filters, but it provides an indication of the net solids production that could be expected from denitrification using ethanol.

SUMMARY AND CONCLUSIONS

Denitrification filters have been used to meet stringent total nitrogen limits for over 30 years. Virtually every facility has historically used methanol as the readily biodegradable carbon source for denitrification. As the result of parallel nutrient reduction initiatives for several major watersheds, there has been a great deal of interest in alternative carbon sources because of the safety concerns associated with methanol, increases in methanol costs, and lapses in availability. Significant research is in progress into the denitrification kinetics, biomass yields, and operating issues associated with these carbon sources.

The dosing requirements and operating issues associated with methanol are well documented at this time. The testing data from the Lower Reedy WWTP closely followed literature values. In addition, the impact of both DO and varying influent nitrate concentrations on the methanol dosage were documented.

The performance testing at McDowell Creek WWTP showed that acetic acid is a viable carbon source for denitrification. Dosage requirements were much higher than suggested in the literature. This is likely due, at least in part, to the high DO content of the filter influent wastewater. In addition, the McDowell plant has a biological phosphorus removal process upstream from the filters and it is possible that PAOs or GAOs in the secondary effluent solids entering and accumulating in the filters may take up some acetic acid.

The performance testing at Scituate WWTP showed that MicroC^{TM} is a good carbon source for denitrification, but some operating challenges were encountered in the form of excess biological growth on the filter influent walls. Like in the case of acetic acid, dosage requirements were a bit higher than expected.

Pilot testing of denitrification filters by Dravo Corporation using ethanol showed that an ethanol to NO_3-N dosage ratio of 2.5, or COD to NO_3-N dosage ratio of 5.2, resulted in good denitrification. This generally agreed with literature values.

These results were used to draw some conclusions regarding carbon use in denitrification filters. First, use of carbon sources such as methanol that promote specialized slow growing biomass populations may be advantageous for selecting against unwanted biological growth. It is suspected that in the MicroC^{TM} and possibly the acetic acid systems, ordinary heterotrophic bacteria with high growth rates can easily accumulate in the filter influent piping, launders and walls, possibly reducing the substrate available for denitrification. The use of acetic acid at the McDowell plant was higher than expected from literature values. This is likely due to high DO concentrations in the filter influent but may also be related to uptake of acetic acid by PAOs and GAOs present in the biological phosphorus removal process effluent solids.

MicroC™ has been successfully implemented in several small denitrification filter applications in Florida. These particular sites require a carbon source intermittently depending on the demand for local water reuse applications. Total nitrogen surface water discharge limits are typically less than 3 mg/L however limits on discharges for reuse applications are generally more moderate and a carbon source is normally not required. Longer filter startup periods with methanol make it difficult for these facilities to quickly transition from moderate levels of denitrification to the high level of denitrification needed to meet the lower total nitrogen surface water discharge limits. These facilities have observed good results feeding MicroC™ because the denitrifying biomass develops quickly. This provides the flexibility to run the denitrification filters on an as needed basis which results in chemical costs savings. Data from the McDowell plant suggests that acetic acid may have similar startup advantages.

Additional work is needed to assess the impacts of switching from one carbon source to another. Since methanol is thought to support a specialized and slow growing biomass, filters that have been operating with methanol may require an acclimation period when switching to another

carbon source, and the reverse also may be true. The work at Scituate showed a successful transition from methanol to MicroC™ over a period of one month, and a virtually immediate transition from MicroC™ back to methanol within a few hours. More operating experience with other carbon sources also is needed to further assess the impacts on biomass yield and backwashing frequency; filter headloss; bumping effectiveness and frequency; propensity for development of excess biomass growth in the inlet piping, launders and walls; and to confirm carbon requirements under conditions of high and lower influent DO concentrations.

ACKNOWLEDGMENTS

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