Wastewater Management Fact Sheet
Denitrifying Filters

INTRODUCTION

Discharge permits for treated wastewater from publicly owned treatment works (POTWs) often include effluent limitations for nutrients. Total maximum daily loads (TMDLs) for nutrients are being developed for many waterbodies throughout the United States. TMDLs and other water quality-drivers have resulted in POTWs having to comply with more stringent effluent limitations for parameters such as total nitrogen (TN).

Untreated domestic wastewater contains ammonia. Nitrification is a biological process that converts ammonia to nitrite and nitrite to nitrate. If standards require that the resulting nitrate be removed, one treatment alternative is the process of denitrification, in which nitrate is reduced to nitrogen gas. One treatment system used for denitrifying wastewater effluent is the denitrifying filter. In addition to the reduction of total nitrogen, this treatment process removes suspended solids from the effluent.

NITRIFICATION/DENITRIFICATION

Nitrification is a microbial process by which ammonia is sequentially oxidized to nitrite and then to nitrate. The nitrification process is accomplished primarily by two groups of autotrophic nitrifying bacteria that can build organic molecules by using energy obtained from inorganic sources—in this case, ammonia or nitrite.

In the first step of nitrification, ammonia-oxidizing bacteria oxidize ammonia to nitrite according to equation (1):

$$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^- \qquad (1)$$

Nitrosomonas is the most frequently identified genus associated with this step, although other genera, including *Nitrosococcus* and *Nitrosospira*, may be involved. The subgenera *Nitrosolobus* and *Nitrosovibrio* can also autotrophically oxidize ammonia.

In the second step of the process, nitrite-oxidizing bacteria oxidize nitrite to nitrate according to equation (2):

$$NO_2^- + H2O \rightarrow NO3^- + 2H^+ + 2e^- \qquad (2)$$

Nitrobacter is the genus most frequently associated with this second step, although other genera, such as *Nitrospina*, *Nitrococcus*, and *Nitrospira*, can also autotrophically oxidize nitrite (U.S. EPA, *Nitrification*, August 2002).

Denitrification is the process by which nitrates are reduced to gaseous nitrogen by facultative anaerobes. Facultative anaerobes, such as fungi, can flourish in anoxic conditions because they break down oxygen containing compounds (e.g., NO_3^-) to obtain oxygen. Once introduced into the aquatic environment, nitrogen can exist in several forms—dissolved nitrogen gas (N_2), ammonia (NH_4^+ and NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and organic nitrogen as proteinaceous matter or in dissolved or particulate phases. The energy reactions are (Metcalf and Eddy, 1979):

$6\ NO_3^- + 2\ CH_3OH \rightarrow 6\ NO_2^- + 2\ CO_2 + 4\ H_2O$ (Step 1)

$6\ NO_2^- + 3\ CH_3OH \rightarrow 3\ N_2 + 3\ CO_2 + 3\ H_2O + 6\ OH^-$ (Step 2)

Overall,

$6\ NO_3^- + 5\ CH_3OH \rightarrow 5\ CO_2 + 3\ N_2 + 7\ H_2O + 6\ OH^-$

The organisms carrying out this process are called *denitrifiers*. In general, they are heterotrophic bacteria that metabolize readily biodegradable substrate under anoxic conditions using nitrate as the electron acceptor. If oxygen is available, these bacteria use it for metabolism before they use the nitrate. Therefore, dissolved oxygen concentrations must be minimized for the denitrification process to function efficiently. Oxygen is typically minimized by avoiding aeration of the wastewater and having a high concentration of biochemical oxygen demand (BOD) so that the microorganisms use all the oxygen.

A readily biodegradable organic compound (a carbon source) must be available for the denitrifiers to use. Because the typical denitrifying filter installation is downstream of aerobic treatment, in which most of the organic material is oxidized, some organic material must be added to the filter influent to sustain the growth of the denitrifiers. The carbon source most often selected is methanol, which is readily degraded under anoxic and aerobic conditions. Other carbon sources, such as acetic acid, also can be used in denitrifying filter systems.

DESIGN FEATURES

Filter Configurations

Denitrifying filters have been utilized for wastewater treatment for a number of years. The combination of denitrification and solids removal was first patented in the 1970s. Since that time, several companies have developed their own denitrifying filters. In addition to meeting TMDL requirements, facilities such as the East Central Regional Water Reclamation Facility in West Palm Beach, Florida, are utilizing denitrification filters as part of an advanced wastewater treatment system to enable them to reuse treated wastewater to augment wetlands and to recharge aquifers (Figures 1 and 2).

There are two main process configurations for denitrification filters commercially available, downflow and upflow continuous backwash filters.

Downflow denitrification filters operate in a conventional filtration mode and consist of media and support gravel supported by an underdrain. Manufacturers include Severn Trent Services (Fort Washington, Pa.), maker of the TETRA Denite system; F.B. Leopold Co. Inc. (Zelienople, Pa.), maker of the elimi-NITE system; and Siemens Water Technology Davco

Figures 1 and 2. Denitrifying filters at the East Central Regional Water Reclamation Facility, West Palm Beach, Florida

Products (Thomasville, Ga.), maker of the Davco denitrification filter.

Wastewater enters a downflow filter over weirs along the length of the filter bed on both sides. Filter effluent is conveyed from the bottom of the filter over a control weir into a clear well. Backwashing is required at regular intervals. Backwashing typically involves air scouring and backwashing with air and water. During the process, nitrate is metabolized to nitrogen gas, which becomes embedded in the filter media. Nitrogen-release cycles are needed to remove these nitrogen gas bubbles that accumulate. The piping for the filter influent and backwash is similar to that of conventional filters.

Upflow continuous-backwash filters differ in that influent wastewater flows upward through the filter, countercurrent to the movement of the sand bed.

Wastewater enters the filter through the influent pipe (where methanol can be added), and then is transported downward through a supply pipe and distributors (Figure 3). The water moves up through the filter media and filtrate is discharged from the upper portion of the filter. The filter media travels slowly downward and is drawn into an airlift pipe in the center of the filter. Compressed air is introduced to the airlift, drawing sand upward and scouring it. At the top of the airlift, the media is returned to the filter bed. Filtered water rises through a separator that removes the light dirt particles by washing them away and returns the large, heavy sand grains to

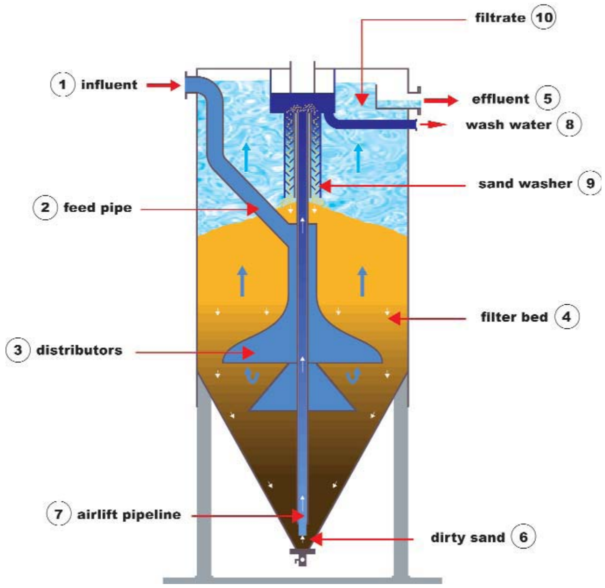

Figure 3. Astrasand upflow continuous-backwash filter.

the top of the filter bed. The reject, or backwash, water continuously exits near the top of the filter. The reject-water weir is set at a lower elevation than the effluent weir to allow clean water to enter the washer and separator continuously by differential head, eliminating the need for typical backwash-supply pumps.

Manufacturers include Parkson Corp. (Fort Lauderdale, Fla.), maker of the DynaSand filter, and Paques bv (Balk, Netherlands), maker of the Astrasand filter. Siemens Water Technologies has a license agreement with Paques to supply this filter in the United States and Canada.

Filter Design Characteristics

When designing a denitrification filter, there are many considerations that should be taken into account by wastewater professionals. Table 1 presents a brief overview of the systems offered by different manufacturers (deBarbadillo et al. 2005). Major design considerations include 1) a manufacturer's experience and 2) the system's performance, which includes influent weir configuration, types of filter media, underdrain, process controls such as backwash and filter control, and methanol feed control.

Filter Influent Weirs

Many downflow denitrification filters are capable of being operated at variable levels and may have a significant drop over the influent weir. This drop can result in the entrainment of dissolved oxygen (DO). The increase in DO reduces the efficiency with which the filter removes nitrate and increases methanol consumption. In order to address this issue, manufacturers have developed different designs to mitigate the problem. The TETRA Denite system has a patented curvilinear weir block to encourage laminar flow down the wall to minimize DO entrainment. The elimi-NITE system can also be installed with a curved stainless steel weir to solve this problem. Additionally, the F.B. Leopold Company has suggested that operating the system in a constant-level mode would reduce the elevation drop from the influent weir, thereby decreasing the level of DO entrainment. Since influent in upflow continuous-backwash filters is conveyed to the feed radials within the filter bed through submerged manifold piping, DO entrainment over the influent weir is less an issue for those filters utilizing this configuration.

Media

The preferred media for each filter manufacturer is also presented in Table 1. The filter media in the TETRA Denite system consists of a monomedia granular sand with a two to three millimeter effective size. Uniform and relatively spherical media reportedly allow for more rolling and contact with other media grains, resulting in more effective backwash and nitrogen-release cycles and, ultimately, lower backwash water volume requirements. Davco filters can be supplied with the same media. Finer media are used with the DynaSand and Astrasand filters that utilize the upflow continuous-backwash filter design.

Underdrain

Early experience with downflow denitrification filters suggested that nozzle underdrains were prone to fouling and failure. To avoid these problems, manufacturers have developed unique block underdrains (Figure 4) (deBarbadillo et al. 2005). Severn Trent Services offers the TETRA T-block underdrain, which is specifically designed for bioreactor service and consists of concrete-filled blocks enclosed in high-density

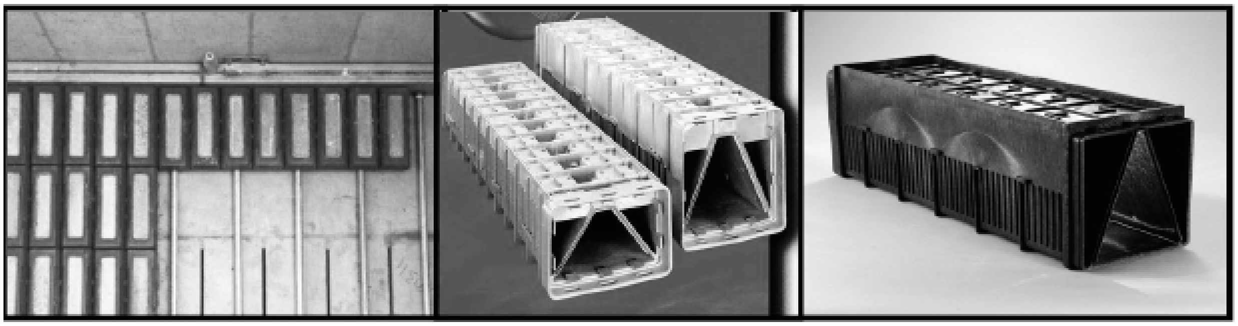

Figure 4. Block Underdrain Systems.

polyethylene (HDPE). F.B. Leopold developed its Universal Type S underdrain, which consists of HDPE blocks. Although existing Davco filters were constructed with pipe lateral underdrains, new installations will be supplied with the Multiblock HDPE underdrain. Upflow continuous-backwash filters do not require an underdrain.

Nitrogen Release Cycle

During the denitrification reaction, nitrogen gas accumulates in the media bed. Wastewater is forced to flow around the gas and increases head loss in the filter. The nitrogen release cycle emits the nitrogen gas into the atmosphere. The TETRA Denite system offers a control package, known as SpeedBump, which pumps backwash water up through the filter for 30 seconds to 2 minutes. The influent valve to the filter remains open to minimize filter downtime. The elimi-NITE and Davco systems offer nitrogen-release cycles that fully close the influent valve, and the additional time required for the nitrogen-release cycle should be accounted for in the filter design. Since the DynaSand and Astrasand upflow systems operate in the same direction that the nitrogen gas travels, and the gas also is drawn into the airlift, a separate degassing cycle is unnecessary.

Backwashing and Filter Controls

During operation of the denitrification filter, solids removed from the wastewater accumulate in the media. Additional solids from the growth of denitrifying bacteria also build up in the filter media. This increases the head loss in the filters. To clean the media, backwashing cycles for the downflow filters are initiated on the basis of increased head loss through the filter or on a timed basis. All three manufacturers of downflow filters offer air scouring and air-water backwash as part of the backwash cycle. Integrated process control systems are offered for the TETRA Denite, elimi-NITE, and Davco filtration systems which control the backwashing, air-scour, and nitrogen-release cycles.

The DynaSand and Astrasand systems operate with a small continuous-backwash stream. A process monitoring tool for the Astrasand filter, the Astrameter system, is used to measure the sand circulation rates at several locations throughout the filter.

Questions remain regarding the bed turnover rate (backwash frequency) and how it relates to maintaining good solids removal while supporting sufficient biomass for denitrification. Available for use with the Astrasand filter, the Astracontrol system was developed to maintain biological activity within the filter under varying conditions.

The control system continuously adjusts the media movement and washing rate to maintain a fixed volume of active biomass in the filter. Studies performed by Siemens Water Systems suggest that optimizing the backwash rate based on hydraulic loads through automation of the airlift provides excellent control of the process (Freed and Pauwels). Parkson Corporation has indicated that changing the bed turnover rate in the DynaSand system might be necessary to

Table 1. Comparison of Denitrification Filter Manufacturers and Equipment					
Manufacturer/ filter	**Severn Trent Services/ TETRA® Denite®**	**F. B. Leopold/ elimi-NITE**	**USFilter/Davco**	**Parkson/ DynaSand**	**Paques and USFilter/ Astrasand**
Flow regime	Downflow	Downflow	Downflow	Upflow	Upflow
Underdrain	T-block; concrete-filled, HDPE jacket	Universal Type S HDPE block	Pipe lateral; or Multiblock HDPE block	None required	None required
Air header arrangement	SS box header; laterals beneath underdrain	SS header across filter; laterals	SS air header; 50-mm (2-in.) laterals	Vertical air lift	Vertical air lift
Media	457 mm (18 in.) graded gravel, 1.8 m (6 ft) of 6 × 9 mesh silica sand, uniformity coefficient 1.35, 0.8 minimum sphericity	381 mm (15 in.) graded gravel, 1.8 m (6 ft) of 6 × 12 mesh sand	2 layers support gravel, 1.8 m (6 ft) of 6 × 9 mesh sand	1.35 to 1.45 mm subround media or 1.55 to 1.65 mm subangular media with uniformity coefficient of 1.3 to 1.6; 2-m (6.6-ft) bed depth	1.2 to 1.4 mm sand, 2-m (6.6-ft) bed depth
Nitrogen-release cycle	Initiated by headloss or time-controlled cycle; Speed Bump controls	Initiated by headloss or time-controlled cycle	Initiated by headloss or time-controlled cycle	None required	None required
Backwash water and air requirement	244 L/min·m^2 (6 gal/min·ft^2); 1.5 m^3/min·m^2 (5 scfm/ft^2)	244 L/min·m^2 (6 gal/min·ft^2); 1.5 m^3/min·m^2 (5 scfm/ft^2)	407 L/min·m^2 (10 gal/min·ft^2); 1.5 m^3/min·m^2 (5 scfm/ft^2)	Continuous through air lift and sand washer	Continuous through air lift and sand washer
Influent weir type	Curvilinear weir block	Curved stainless steel weir	Varies	Feed radials at bottom of unit	Feed radials at bottom of unit
Backwash flow as percent of forward flow	<5; often 1 to 2	2	Not documented	3 to 5	3 to 12
Patented features	T block underdrain, curvilinear weir block, Speed Bump, TetraPace, TetraFlex	Universal underdrain and features	None	None	None in United States; Astracontrol in Europe

HDPE = high-density polyethylene.

SS = Stainless steel

meet a specific requirement. However, the company has not seen a need to adjust it during routine operation

Table 1 Courtesy of Christine deBarbadillo

Methanol Feed Control System

Methanol is usually dosed to the filter influent before it is divided among the filter cells. In the Denite system, methanol is dispensed on the basis of the filter influent flow rate and the concentrations of nitrate in the influent and

effluent, as measured by an online nutrient analyzer. The manufacturer guarantees no net increase in total organic carbon across the filter when this control system is used.

The other manufacturers suggest using the filter influent flow rate and nitrate concentration to determine the methanol dosage through a flow-paced or feed-forward automatic control system. Although a feed-forward control scheme can reasonably match methanol dosing to actual requirements, periods of slight overdosing and the resulting increase in concentrations of biochemical oxygen demand (BOD) in the filter effluent might be difficult to avoid. In cases in which effluent BOD and nitrate-nitrogen limits are less stringent, the need for a high level of methanol control is related to optimizing chemical usage.

Costs

There are several factors that are related to a denitrification filter system's capital costs. Depending on the application and overall effluent requirements, it might be desirable at times to use a more conservative design for filters in meeting the required limit. Alternately, pilot testing can be conducted to verify the design loadings. Another factor that may affect the overall cost of the project includes whether the influent and backwash piping and the valves associated with downflow filters are installed outdoors or housed in a building.

In addition to capital cost, operational costs are also important. The energy costs associated with backwashing, air-scour, and nitrogen-release cycles must be considered, along with a proper accounting of the frequency of these operations. The cost of "retreatment" of spent backwash water must also be included: Filters using only 2 percent of the forward flow for backwashing have a lower cost for treatment than those that consume greater amounts of backwash water. Finally, the ability to optimize methanol dosages can affect the operating cost significantly. Some facilities have reduced their chemical consumption as much as 30 percent after implementing more efficient control systems.

Costs will differ for new plants and retrofits. Retrofit costs are more site-specific and vary considerably for any given size category. Retrofit costs are based on the same factors as new plants, in addition to the layout and design of the existing treatment processes. A case study performed for the Maryland Department of the Environment suggests costs in dollars per pound of total nitrogen removed can range from $0.55 to $7.69. For these examples, this equates to a cost of approximately $1.46 per gallon of wastewater treated (Maryland Department of the Environment, 2005).

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