Nitrifying Trickling Filter Provides Reliable, Low-Energy, and Cost-Effective Tertiary Municipal Wastewater Treatment of a Lagoon Effluent

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ABSTRACT

The case study described in this paper demonstrates that the nitrifying trickling filter (NTF) is a reliable and robust bioreactor. The studied NTF was designed to oxidize ammonia-nitrogen (NH_3-N) remaining in the effluent stream of an aerated lagoon that is located in Newton, Mississippi, USA. NTF performance data was collected during a period beginning in June 2007 and ending in January 2010. An analysis of the data demonstrated that the NTF consistently met, amongst other permitted criteria, a moderately stringent permit limit requiring an annual average NH_3-N concentration less than 2.0-mg/L remaining in the effluent stream. Comparison of operating costs revealed that the NTF evaluated in this study required approximately one-third of the power required to meet the same treatment objective with a moving bed biofilm reactor (MBBR). However, the NTF required a slightly more foot print than the MBBR (e.g. 90 vs. 80 m^2) to meet the treatment objective. The studied NTF was designed using generally accepted criteria defined throughout this paper. The NTF used medium-density modular plastic trickling filter media comprised of corrugated plastic sheets. The required biofilm surface area, and therefore bioreactor volume, was defined based on a 0.65-g NH_3-N/m^2/d zero-order nitrification rate and a 0.1-kg/m^3/d five-day biochemical oxygen demand (BOD_5) load at 12°C. The method for calculating NTF ventilation is demonstrated. Implementation of the NTF design and construction included some unique features: (1) the NTF influent pumps were located to provide NTF effluent recirculation (which provides proper media wetting, controls biofilm thickness and minimizes macro fauna accumulation), (2) use of influent pump(s) speed control to optimize the NTF superficial hydraulic application rate (or Spülkraft), (3) the ventilating area was conservatively designed to maximize airflow, and therefore process oxygen, for the nitrification process (i.e., 0.1-m^2 (1.0-ft^2) open area per 2.4-m (8.0-ft) of NTF periphery), and (4) the application of a column and pier support system to facilitate simple installation and increased air flow.

KEYWORDS: Nitrifying Trickling Filter; NTF; Nitrification; Biofilm; Reactor; Aerated Lagoon; Ventilation; Design; Energy; Efficient; Operating Cost.

INTRODUCTION

Background of the NTF

NTFs are a reliable and cost effective mean for NH_3-N conversion. The following design practices have been demonstrated in full-scale application: (1) use medium-density XF media to optimize hydraulic distribution and oxygenation, (2) use mechanical ventilation, (3) periodically alternate the lead NTF to avoid patchy biofilm development in the lower reaches of the second-stage unit, (4) the influent should be secondary effluent to minimize bacterial competition for substrates inside the biofilm, (5) maximize wetting efficiency to avoid the formation of dry spots, (6) dose the NTF at a rate that will minimize the accumulation of macro fauna, (7) equalize NH_3-N laden supernatant from solids processing operations to even out diurnal load variability (Daigger and Boltz, 2010).

Benefits to NTFs include low energy consumption, stability, operational simplicity, and reduced sludge yield. The reduced sludge yield and resulting low total suspended solids concentration in the NTF effluent stream has led some units to be constructed without downstream liquid-solids separation units. This is dependent on site specific treatment objectives and effluent water quality standards. NTFs having 6- to 12.2-m (20- to 40-ft) modular plastic media depths has demonstrated improved performance. NTFs have been constructed with depths up to 12.8 m (~42 ft) (Daigger and Boltz, 2010). Shallower units can operate as a two-stage system. Recirculation should be minimized to that required for biofilm thickness control in order to maximize NH_3-N concentration (i.e., maintain a high driving force) (Parker et al., 1997).

Parker (1998; 1999) described nitrification efficiency in NTFs containing either XF or VF synthetic media types. Table 1 summarizes his observations, which demonstrates that zero-order ammonia-nitrogen flux rates are greater for XF than VF media.

Table 1 Reported Zero-Order Nitrification Rates for Vertical and Cross Flow Media (after Parker, 1998; 1999)

Location	**Reference**	**Media Type**	J_N^0 (g/m^2/d)	**Temperature Range**(°C)
Central Valley, Utah	Parker et al. (1989)	XF 140	2.3 - 3.2	11 to 20
Malmo, Sweden	Parker et al. (1995)	XF 140	1.6 - 2.8	13 to 20
Littleton/Englewood, Colorado	Parker et al. (1997)	XF 140	1.7 - 2.3	15 to 20
Midland, Michigan	Duddles et al. (1974)	VF 89[1]	0.9 - 1.2	7 to 13
Lima, Ohio	Okey and Albertson (1989)	VF 89[1]	1.2 - 1.8	18 to 22
Bloom Township, Illinois	Baxter and Woodman (1973)	VF 89[1]	1.1 - 1.2	17 to 20

[1] fully corrugated

Factors contributing to the enhanced performance of NTFs may be improved oxygen transfer efficiency resulting from the increased number of media interruptions and improved oxygenation (Gujer and Boller 1986; Parker et al., 1989). Autotrophic nitrifying biofilms are thin when compared with the heterotrophic biofilms that are primarily responsible for BOD_5 removal; therefore, medium-density XF media is typically used in NTFs. However, there is a propensity to develop dry pockets when high-density modular plastic media is used (Parker et al., 1989).

Description of the Facility

The wastewater treatment plant (WWTP) in Newton, MS, is an aerated lagoon system (Figure 1), consisting of a series of four (4) cells of which the first three (3) are long and narrow to support a plug flow operation. The fourth is irregularly shaped due to site constraints. The cells have a combined surface area of 50,000 m^2 (12.3 acres) and a water depth of 3.0-m (9.0-ft) at the levees, providing an overall hydraulic retention time (HRT) of 27 days. The WWTP was originally designed to meet secondary five day biochemical oxygen demand (BOD_5) and total suspended solids (TSS) treatment limits only, with an average design flow of 0.77 million gallons per day (mgd) (or 2,915 m^3 per day). The newly implemented ammonia limit of 2.0 mg/L exceeded the original process design capability of the facility for consistent nitrification, especially at lower operating temperatures associated with lagoon treatment during winter months. For example, the effluent ammonia of the existing aerated lagoon system was averaging 13 mg/L, and as high as 20 mg/L during cold temperature period. Table 2 lists the current plant effluent limits.

Table 2 Effluent limits for Newton, MS wastewater treatment plant

Effluent Characteristics	Effluent Limits (Yearly Average)
BOD_5	10 mg/L
TSS	30 mg/L
NH_3-N	2.0 mg/L
DO	greater than 6.0 mg/L
pH	6-9

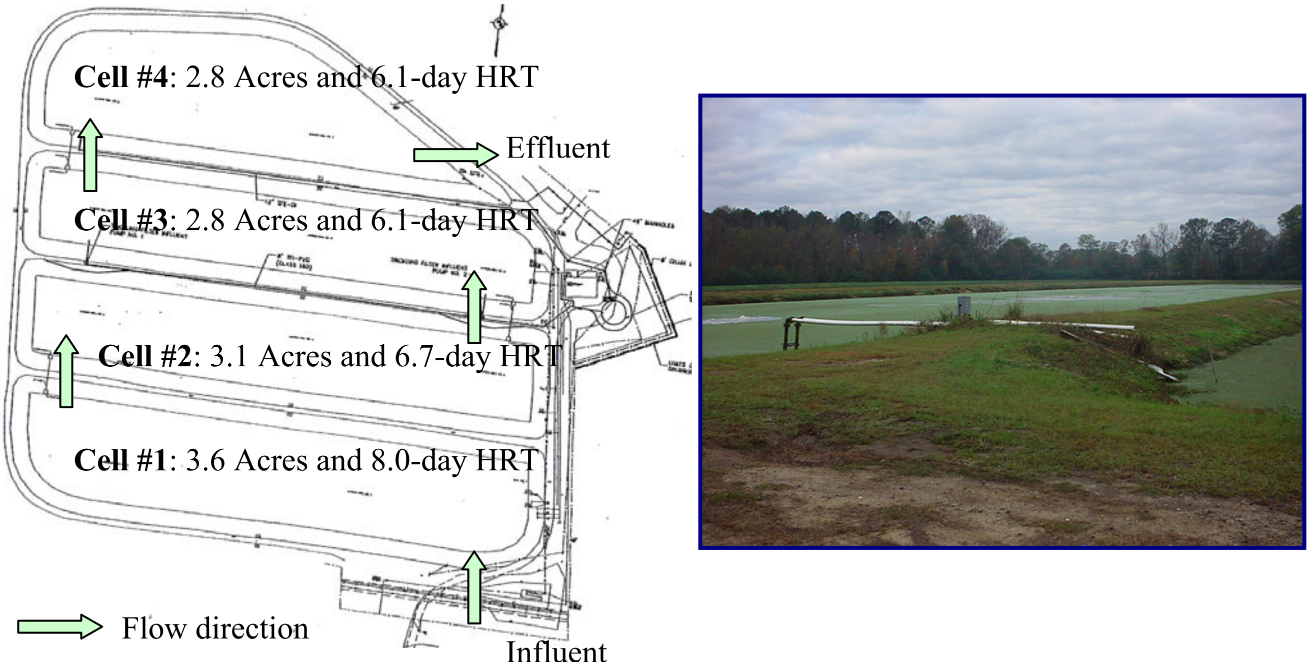


Figure 1 Layout and aerial photo of the aerated lagoon system in Newton, MS

Biofilm Technologies for Lagoon Effluent Polishing

Nitrification in an aerated lagoon may be difficult due to several factors including oxygen limitation, poor distribution of influent wastewater and mixing, low operating temperatures, and also the limited ability to retain slow-growing autotrophic nitrifiers. Biofilm technologies such as the trickling filter and moving bed biofilm reactor (MBBR) have been shown able to retain dense nitrifying biomass inventory on a supporting media surface (Parker et al., 1989, Wessman and Johnson, 2006, and Hewell, 2009), therefore independent of the suspended biomass in a typical activated sludge or lagoon process. A number of criteria, including maximizing the use of existing assets, minimizing operational requirements, and minimizing life-cycle costs were applied to determine the most feasible biofilm technology for the Newton, MS upgrade. The NTF alternative was eventually selected to bring the plant into compliance with the ammonia limit due to its process capability and reliability and also cost-effectiveness.

Objectives

This case study is intended to evaluate long-term performance data collected from a NTF treating effluent from an aerated lagoon system at the City of Newton, MS Wastewater Treatment Plant. In addition to evaluating system performance, the study is also aimed at discussing design criteria (according to Boltz et al., 2010) and implementation methodology of the NTF and also comparing the NTF operating costs with a hypothetical MBBR process.

DESIGN CONSIDERATIONS OF THE NTF

Process Design of Combined Carbon Oxidation and Nitrification Trickling Filter

The NTF at Newton, MS was sized based on an influent BOD_5 and NH_3-N concentrations of 30 and 20 mg/L, respectively, at the average design flow rate of 0.77 mgd. Per the published performance data for trickling filters (e.g. $TKN_{OX}=1.086 \cdot [BOD_5:TKN]^{-0.44}$ with a standard deviation of 0.175 g TKN/m^2/d at 15°C) (Boltz et al., 2010; Boltz, 2010), a zero-order nitrification rate of approximately 0.65 g NH_3-N/m^2/d at a winter temperature of 12°C was developed for determining the overall media volume/surface area requirement. A dense structured sheet plastic media with a specific surface area of 157 m^2/m^3 (48 ft^2/ft^3) was selected to minimize the footprint of the NTF and also because of the expected relatively low biomass yield from a nitrifying biofilm. The NTF was ultimately sized with a diameter of 10.6-m (35-ft) and a media depth of 6.1-m (20-ft). This was also consistent with the ammonia percentage removal requirement (e.g. ~90% from 20 to 2 mg/L for the permit) at the resulted NTF organic load of 0.11 kg/m^3-day (or 7 lbs/1,000 ft^3-day) (US EPA, 2000).

NTF Influent Pumps

Two centrifugal influent pumps, each with a maximum pumping capacity of 44.2 liters per minute, lpm (700 gpm) were located in the influent (or east) and effluent (or west) sides of Cell #3, respectively for redundant operation and potential process control flexibility. The treated wastewater from the trickling filter can be returned to either the middle of the Cell #3 as recirculation flow or the inlet of the Cell #4 for final clarification. The east pump was intended to operate during winter months to minimize the exposure of wastewater to the cold atmosphere for an extended HRT and therefore reduce the negative impact of low temperatures on the nitrification performance of the trickling filter. The west pump was designed to provide flow recirculation to the trickling filter by pumping mixed wastewater from both Cell #2 and the filter effluent as returned to the middle of the Cell #3.

The influent to the trickling filter was metered and controlled at a constant flow rate of 22.1 lpm (350 gpm) in order to maintain a consistent filter wetting rate (e.g. about 23.5 m^3/m^2-d or 0.4 gpm/ft^2) and also to provide better control for the hydraulically propelled distributor (Figure 3). Flow fluctuation from the existing pumping rate of 22.1 lpm (350 gpm) was equalized through recirculation between cells. Plugging of trickling filter media with lagoon algae was not encountered as the influent pipes of the pumps were submerged about 1.0-m (3-ft) below the surface where no or limited algae was present.


MAR 20 2007

Figure 2 Filter influent pumps in Cell #3


MAY 23 2008

Figure 3 Filter influent meter

Hydraulically Propelled Distributor

A hydraulic propelled distributor with brake orifice assemblies in each arm was designed for flow distribution over the structured sheet media, primarily due to the enhanced control of the influent pumps for a constant flow rate. The hydraulic reaction distributor has a stationary center weldment supporting a turntable base from which a rotating assembly with distribution arms is suspended (Figure 4). The center assembly consists of a stationary support pier (Figure 5) anchored to the concrete center column which elevates and supports the main bearing assembly. The pier contains port cuts, which serves as a weir to allow for free water discharge from the stationary pier into rotating tub (Figure 6). Each distribution arm has openings fitted with flow spreaders and replaceable orifice plates to distribute the flow evenly from each hole (Figure 7).

The hydraulically propelled distributor has minimum and maximum flow capacities of 300 and 700 gpm, respectively and it also has minimum and maximum operating speeds of 0.95 and 2.0 rpm, respectively. The minimum and maximum flows and operating speeds of the distributor provide equivalent SK in the range of 3-16 mm/pass, which appears consistent with the typical dosing rates for a rock filter (WEF, 1998). However, no performance reduction was observed as a result of the low operating SK values for a structured sheet media NTF.

Figure 4 Overview on the hydraulically propelled distributor

Figure 5 Stationery support pier for the distributor

Figure 6 Discharging weir on the stationery supporting pier

Figure 7 Distributor arm and flow spreaders

Ventilation Requirement for the NTF

Air requirement for the design organic and ammonia loads was determined to be about 2,600 standard cubic feet per minute (scfm) using the following equations (1-3) (WEF, 1998).

$$\text{Oxygen Supply (kg/kg BOD}_5\text{)} = (40\ \text{kg/kg}) \cdot (0.8 \cdot e^{-9L_B} + 1.2 \cdot e^{-0.17L_B} + 4.6 \cdot \text{TKN}_{\text{OX}} / \text{BOD}_5) \cdot (\text{PF}) \qquad (1)$$

$$\text{Air Rate, N, m}^3\text{/hr} = \frac{(\text{Oxygen Supply, kg/d}) \cdot (3.5\ \text{N, m}^3\text{/kg Oxygen})}{24\ \text{hr/d}} \qquad (2)$$

$$\text{A, m}^3\text{/hr} = (\text{N, m}^3\text{/hr}) \cdot \left(\frac{273 + t_o}{273}\right) \cdot \left(\frac{760}{760 - P_o}\right) \qquad (3)$$

Where:

L_B = Organic load of the NTF, 0.11 kg/m^3-day (or 7.0 lbs/1,000 ft^3-day)
TKN_{OX} = Influent TKN - Net Yield Organic N - Effluent TKN, kg/day
PF = Peaking factor, 2.5 for the Newton, MS NTF
t_o = Ambient air temperature, 30°C
P_0 = Site pressure, 744 mm Hg at a site elevation of 500-ft

The headloss (or pressure drop) through plastic media as induced by the required air flow rate of 2,600 scfm was estimated to be approximately 1.74×10^{-2} Pa (7.0×10^{-5} inch of water) based on the following equations (4-5) (WEF, 1998). Multipliers of 1.6 and 1.5 were also considered in the calculation to account for the cross-flow media and inlet and other head losses.

$$\Delta P = N \cdot (\frac{v^2}{2g}) \tag{4}$$

$$N_p = 3.15 \cdot D \cdot e^{(6.62\times10^{-5})\cdot(L/A)} \tag{5}$$

Where:

v – Superficial air velocity, m/s (ft/sec)
g – Acceleration of gravity, 9.8 m/s^2 (or 32.2 ft/sec^2)
N – Tower resistance, number of velocity heads lost in tower
N_p – Packing loss, velocity heads
L – Liquid loading, lbs/hr (kg/hr)
A – Tower top surface area, ft^2 (m^2)
D – Media depth, ft (m)

The driving pressure as resulted from a natural draft was estimated to be 0.131 Pa (5.25×10^{-4} inch of water) downflow based on the equations of (6) and (7) (WEF, 2000). This far exceeds the air flow requirement as determined by the process demands, indicating natural draft should be adequate for the NTF operation if the air inlets do not restrict flow.

$$T_m = \frac{T_1 - T_2}{\ln(\frac{T_1}{T_2})} \tag{6}$$

$$\Delta P = 7.64 \cdot (\frac{1}{T_0} - \frac{1}{T_m}) \cdot D \tag{7}$$

Where:

T_0 – Outside temperature, 540 °R (or 80 °F)
T_m – Inside or water temperature, 538 °R (or 78 °F)
D – Media depth, ft (m)

Eight 18-inch diameter openings at the base of tower provide natural convective ventilation for the nitrification process (Figure 8). The highest point of each opening was maintained below the supporting grating and the bottom of media to prevent any restriction of airflow in the inlets (Figure 9). The ventilating area to the filter periphery ratio is about 0.1 m^2 per 2.6-m (or 1 ft^2 per 8.0 ft) in Newton, MS, which is higher than the MOP ventilation recommendation of 0.1 m^2 per 3.0-4.6 m (1 ft^2 per 10-15 ft) filter periphery in order to ensure sufficient air for the nitrification process.

Figure 8 Ventilation openings on the base of the filter

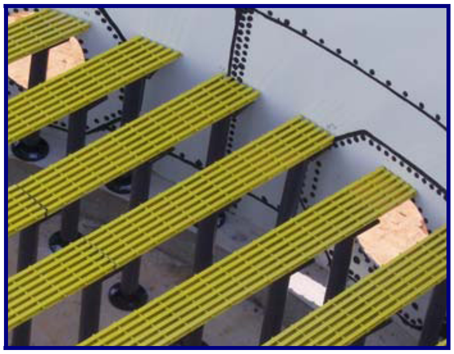


Figure 9 Ventilation openings below the bottom of the grating

Media Support Structure

The trickling filter support system utilized standard column design to handle the construction and operating loads of modular trickling filter media and was tested to 10,900 kg (24,000 lbs) capacity. The system consists of main PVC support columns with caps and slope-adjustable bases designed to interface with the integral support grating and concrete base structure (Figure 10). The column spacing is determined through evaluation of the loads applied due to the height of media and associated biological film generated which will be transmitted to the support grating. Typical grating span from pier-to-pier is about 0.6-0.9 m (2-3 ft) and spacing between gratings is about 0.6 m (2 ft) which is consistent with the media block support location dimensions (Figure 11). Compared to conventional formed-in-place concrete supports, the PVC column support system shows the benefits of lower cost, reduced blinding of the media flutes for increased air flow and decreased solids accumulation, flexibility in air plenum design, and quick and easy installation.

Figure 10 Column and pier media supporting system

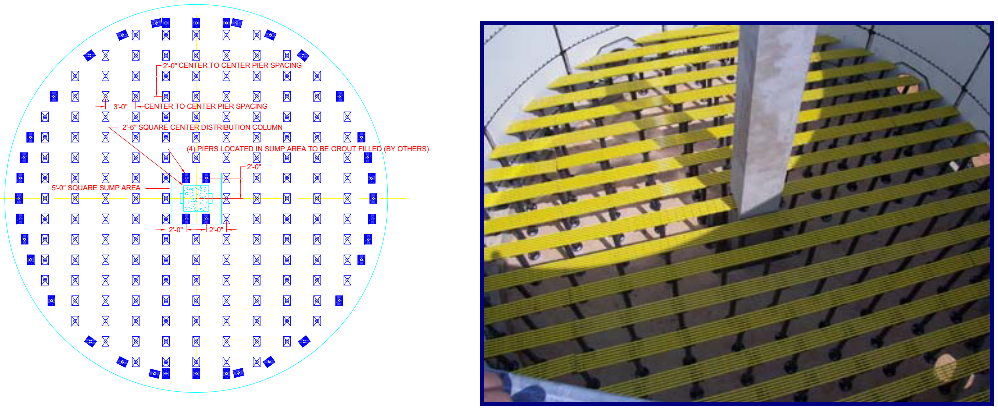


Figure 11 Layout and photo of column and pier media supporting system

Under Drain of the NTF

A clearance of 1.37-m (4.5-ft) between the bottom of the plastic media and the filter floor at the outside wall was maintained to allow for free air flow and ventilation. The filter floor is sloped towards an effluent well located in the center of the filter, where wastewater flows to either Cell #3 or #4 by gravity.

Figure 11 Trickling filter under drain well and pipe

PERFORMANCE

Ammonia Removal in the NTF

The NTF was started up during the coldest temperature period in late January, 2007 and significant nitrification did not occur initially until the wastewater temperatures rose to greater than 15^{o}C after about six weeks. However, the performance data collected from the past three years have shown the acclimated NTF was able to handle the temperature fluctuations and achieve consistent nitrification and meet the ammonia discharge limits. A single effluent ammonia spike was observed during the early filter operation (e.g. June 2007) due to a concurrently increased BOD and TSS loads to the filter (Figure 12); however, individual increases of either BOD or TSS concentrations to the NTF later on (e.g. November 2007 and January 2008) did not compromise the nitrification performance. The nitrification activity of the filter was also confirmed by the fact that a significant amount of alkalinity was consumed in the filter (Figure 13). This was equivalent to approximately 6.8 g alkalinity consumed per 1.0 g of ammonia removed, close to the theoretical alkalinity requirement for a nitrification process (e.g. 7.1 g alkalinity per g of ammonia). The slight deviation of alkalinity consumption as compared to the theoretical number may be attributed to the alkalinity credits resulted from a possible denitrification process as occurred in the filter when the nitrate-rich filter effluent is mixed with the raw wastewater from Cell #2 and returned to the filter.

The ammonia concentration observed in the plant effluent was shown slightly higher than those measured directly from the filter effluent. For example, on August 9, 2007, ammonia concentrations of the filter influent, effluent, and the plant effluent were 17.5, 0.6, and 3.1 mg/L, respectively. Sampling of wastewater in different locations and depths in Cell #4 (Figure 14) confirmed that ammonia release was occurring likely as a result of anaerobic digestion of sludge. This was also evidenced that the deeper the samples were taken, the higher the ammonia levels were detected (Figure 15). The sludge sampling results in Cell #4 has led the plant to temporarily close the cross connection between Cell #3 and #4 to facilitate direct discharge of treated effluent from Cell #3 prior to scheduling a sludge removal event in Cell #4.

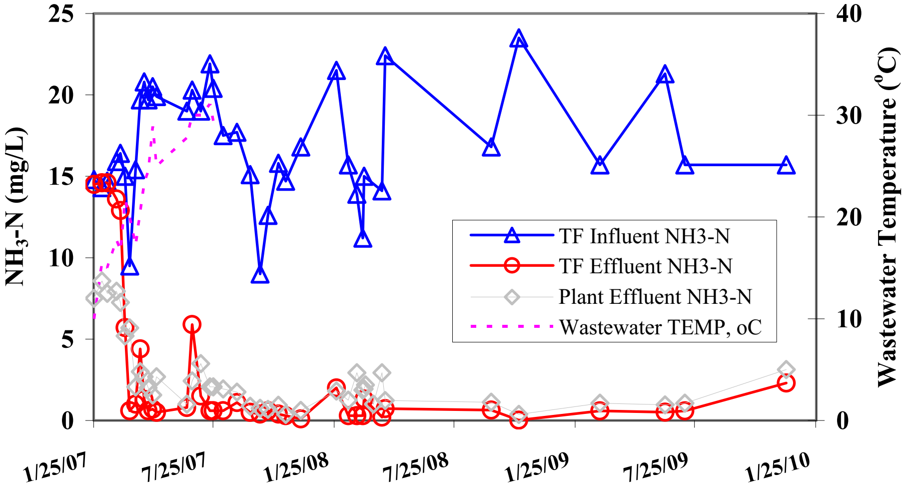


Figure 12 Ammonia removal performance of the NTF at Newton, MS

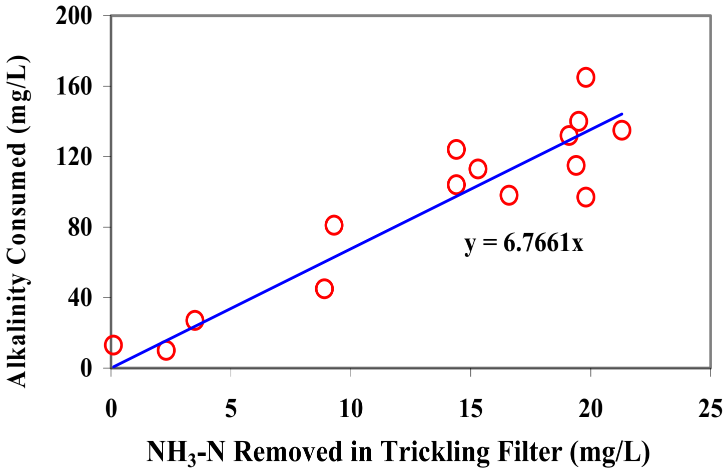


Figure 13 Correlation between alkalinity consumption and ammonia removed in the NTF

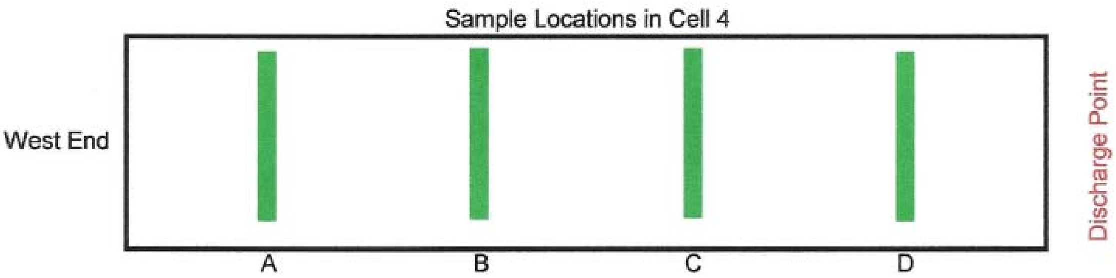
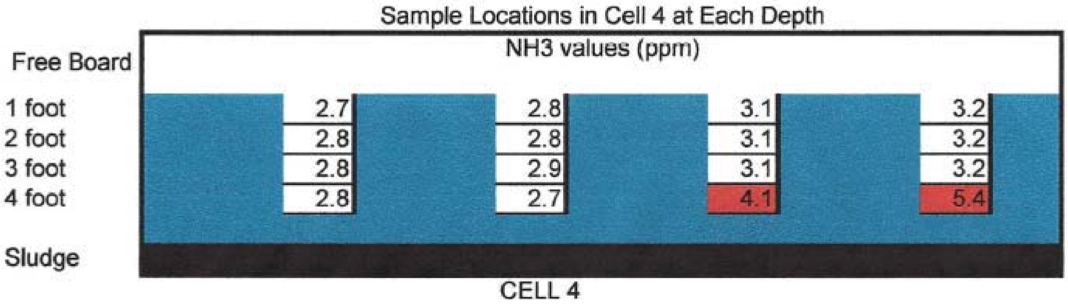


Figure 14 Schematic of wastewater sampling location in Cell #4



1 foot	2.7	2.8	3.1	3.2
2 foot	2.8	2.8	3.1	3.2
3 foot	2.8	2.9	3.1	3.2
4 foot	2.8	2.7	4.1	5.4

Figure 15 Ammonia profiles at different locations and water depth in Cell #4

Nearly complete ammonia removal was achieved in the trickling filter (Figure 16), partially because of the light ammonia loads to the filter (e.g. less than 0.6 g/m^2/d as opposed to the design nitrification rate of 0.65 g/m^2/d). The correlation between ammonia removal rates and temperatures yielded a temperature correction coefficient of $\theta=1.021$ for the NTF system (Figure 17), which was different from the temperature coefficient of 1.035 as used in the initial process design. However, the interpretation of the applicability of the variable temperature correction coefficient should be cautious as the influence of temperatures on the nitrification rate in a NTF also depends on organic loads, limiting substrates (oxygen or ammonia), hydraulics, and wetting efficiency (WEF, 1998).

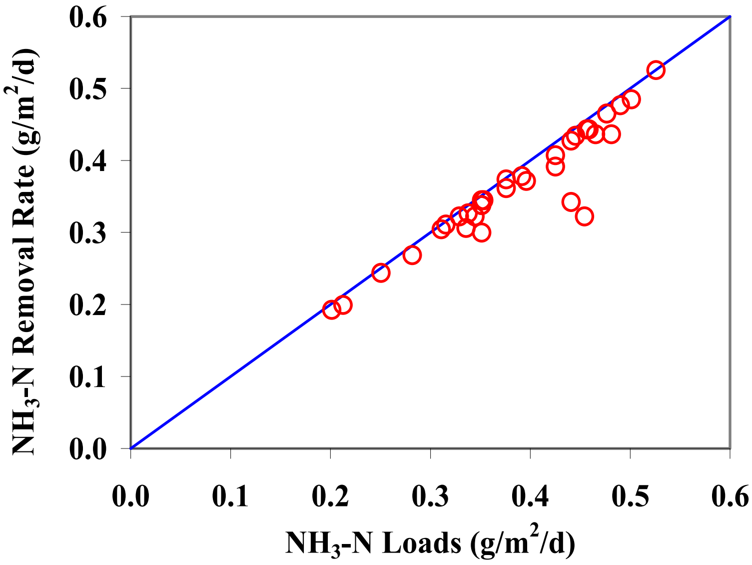


Figure 16 Ammonia removal rates versus ammonia loads to the NTF

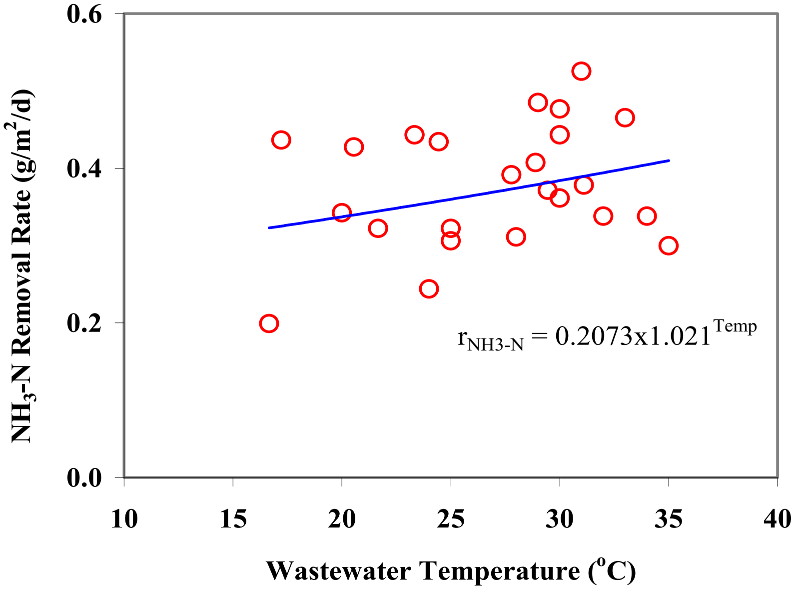


Figure 17 Effect of temperature on ammonia removal rates in the NTF

BOD and TSS Removal

The influent BOD concentrations to the trickling filter ranged from about 10 to 45 mg/L. No apparent BOD reduction was seen during early sampling prior to August 2007 (Figure 18). This may be primarily due to the presence of TSS in the filter effluent. Settling of solids in the Cell #4 contributed to an overall enhanced BOD polishing with an average plant effluent BOD of 5.0 mg/L. The filter influent and effluent TSS concentrations were comparable (Figure 19), indicating low solids yields from the BOD polishing and nitrification processes. The solids as sloughed off from the trickling filter has also shown good settleability and the plant effluent TSS were averaging approximately 8.0 mg/L.

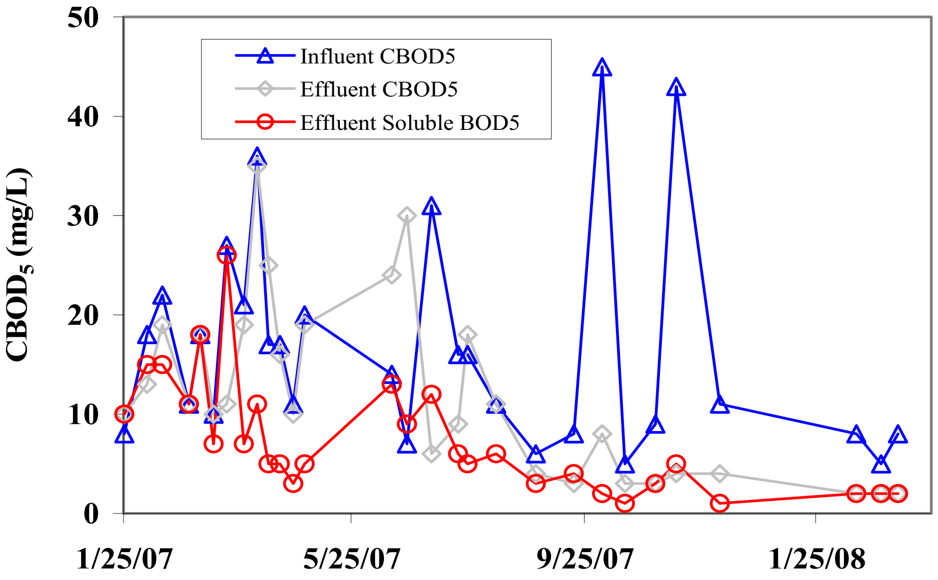


Figure 18 CBOD$_5$ concentrations in the filter influent, filter effluent, and the plant effluent

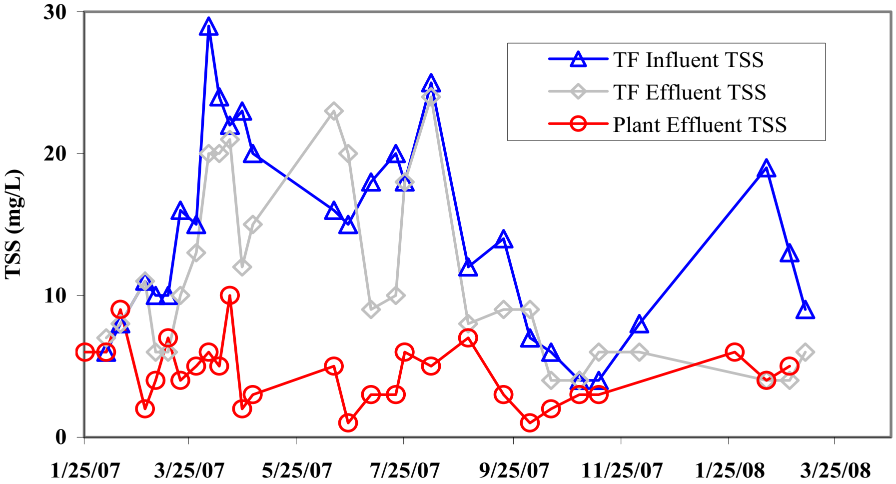


Figure 19 TSS concentrations in the filter influent, filter effluent, and the plant effluent

Comparison of the NTF to the Activated Sludge and MBBR Processes

In addition to providing reliable ammonia removal, the NTF also offers lower operating costs than either activated sludge or Moving Bed Biofilm Reactor (MBBR) processes. The only power requirement for the NTF system was using the influent pumps to lift the wastewater to the top of the filter and drive the rotating distributor. Saturated dissolved oxygen conditions were often present in the trickling filter effluent, which also eliminated the re-aeration (or additional power) need to meet the effluent DO limit of 6.0 mg/L in Newton, MS. In contrast, MBBR and conventional activated sludge processes require significant power to operate blowers in order to provide sufficient air for diffusers that mix and aerate the wastewater continuously. Additional air may be also required for the re-aeration process as the conventional activated sludge and MBBR processes are often operated at a residual DO concentration less than 6.0 mg/L. The return sludge pumps of the activated sludge process also require additional power. Estimates of the power required (Table 3) shows the NTF consumes only 30 % and 55 % of the power required by the MBBR and activated sludge processes, respectively.

TABLE 3 Comparison of Operational Cost between NTF, Activated Sludge, and MBBR

	Trickling Filter	**Activated Sludge**	**MBBR**
Design flow, mgd	0.77	0.77	0.77
Design organic load removed, kg/d (lbs/d)	58.4 (129)	58.4 (129)	58.4 (129)
Design ammonia load removed, kg/d (lbs/d)	52.6 (116)	52.6 (116)	52.6 (116)
AOR, kg O_2/d (lbs O_2/d)	311.7 (686)	311.7 (686)	311.7 (686)
Type of diffuser	Natural Draft	Fine Bubble	Coarse Bubble
Residual D.O., mg/L	N/A	2.0	5.0
SOR, kg O_2/d (lbs O_2/d)		661.8 (1,456)	(973.2) 2,141
Influent pump, kW (hp)	7.5 (10)	N/A	N/A
RAS pumps, kW (hp)	N/A	3.7 (5)	N/A
Blower power, kW (hp)	N/A	9.7 (13)	23.9 (32)
Total power, kW (hp)	7.5 (10)	13.4 (18)	23.9 (32)

On the other hand, the MBBR may require less foot print when compared to the NTF, primarily because the MBBR biofilm carrier has a higher specific surface area (e.g. 500 m^2/m^3 or 150 ft^2/ft^3) than the NTF media (e.g. 157 m^2/m^3 or 48 ft^2/ft^3 for this study). However, the difference of the foot print requirements between the NTF and MBBR may be reduced because the NTF typically contains fill media up to 100% of the tank volume (as compared to a typical 50-60% media fill for a MBBR reactor) and is also able to stack a media depth up to 42-ft (as opposed to a typical side water depth (SWD) of 10-ft for a MBBR reactor). For example, it was estimated that the MBBR would require a foot print of approximately 80-m^2 for the Newton, MS WWTP upgrade, assuming an ammonia surface flux rate of 0.7-g NH_3-N/m^2/d, a SWD of 10-ft, and 60% media fill (Hewell, 2009). This was only slightly less than the foot print requirement of the NTF (e.g. approximately 90-m^2 at the filter diameter of 10.6-m or 35-ft).

CONCLUSIONS

This case study has demonstrated that the NTF system can be an effective tertiary process to an aerated lagoon to achieve reliable nitrification. Performance data collected for more than two years has shown that the NTF was able to consistently meet the ammonia discharge limit of 2.0 mg/L. The comparison of operating energy costs reveals that the NTF with corrugated modular plastic media is significantly lower than other fixed-film alternatives, and as low as one third of the energy consumed by a MBBR process. Despite having less media specific surface area, the NTF required a comparable foot print to the MBBR system, mainly because the NTF has a higher media fill and is less restrictive on constructing a deeper NTF tower than a MBBR reactor.

The design of the NTF involved the use of generally accepted design criteria based on the Manual of Practice (Boltz et al., 2009), including sizing the media surface area requirement or bioreactor volume using a zero-order nitrification rate of 0.65 g NH_3-N/m^2/d and a BOD_5 load of 0.1-kg/m^3/d at 12°C and determining the ventilation requirement. Implementation of the NTF design and construction included some unique features: (1) the NTF influent pumps were located to provide NTF effluent recirculation (which provides proper media wetting, controls biofilm thickness and minimizes macro fauna accumulation), (2) use of influent pump(s) speed control to optimize the NTF superficial hydraulic application rate (or Spülkraft), (3) the ventilating area was conservatively designed to maximize airflow, and therefore process oxygen, for the nitrification process (i.e., 0.1-m^2 (1.0-ft^2) open area per 2.4-m (8.0-ft) of NTF periphery), and (4) the application of a column and pier support system to facilitate simple installation and increased air flow.

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