

Florida Passive Nitrogen Removal Study

Additional Monitoring

Prepared for:

Florida Department of Health
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Bureau of Onsite Sewage Programs
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Report Preparation

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Executive Summary

Approximately 2.5 million onsite wastewater treatment systems (OWTS) are currently permitted in the State of Florida. Population growth, exurban development trends, and the cost and energy requirements of centralized infrastructure make it likely that distributed infrastructure will continue to be used for the management of a large portion of domestic sanitary water generated in Florida. The vast majority of onsite systems include a septic tank for primary treatment, followed by dispersal into the environment using soil adsorption systems. Nitrogen removal in these typical systems is limited. Nitrogen loading from onsite systems is a potential concern in Florida, depending on the sensitivity of the water environments, the number and density of onsite installations, their proximity to receiving waters, and processes in subsurface soil media.

This Florida Passive Nitrogen Removal Study (PNRS) was undertaken to investigate alternative methods to remove nitrogen in onsite systems. A primary consideration was to evaluate systems that were “passive” in nature, with limited reliance on pumping and forced aeration. A guiding principal for the PNRS was the specific definition of a “passive” nitrogen removal system as one that contains only a single liquid pump, no mechanical aerators, and that uses reactive media. The PNRS was specifically intended to perform a literature review of passive nitrogen removal technologies, perform an experimental evaluation of passive systems and candidate media, perform an economic analysis of such systems, and make recommendations regarding deployment of passive nitrogen systems.

Experimental Evaluation

The Passive Nitrogen Removal Study entailed operation of three two-stage filter systems to evaluate enhanced nitrogen removal using two-stage passive nitrogen removal systems. Experiments were performed using actual septic tank effluent at a field site in Hillsborough County, Florida. In the original study, the three systems were operated for 60 days on septic tank effluent. Two of the two-stage filter systems achieved over 97% total nitrogen removal and 98% total inorganic nitrogen removal, with average effluent ammonium nitrogen and nitrate+nitrite nitrogen concentrations of less than 0.7 mg/L and 0.5 mg/L, respectively (Smith et al., 2008). High nitrogen removal performance was achieved using clinoptilolite and expanded clay media in the unsaturated Stage 1 filter, and elemental sulfur in the anoxic denitrification filter (Stage 2).

This report presents the results of additional operation and monitoring following the original study. Operation of the three two-stage filters was extended by an additional 186 days, for a total duration exceeding eight months. Nitrogen removal performance of the clinoptilolite/75% sulfur and expanded clay/60% sulfur systems was similar for the extended operation (Days 123 to 245) to the initial 60 day period. The average removal efficiency of these systems for Days 123 through 245 was greater than 95% for Total Nitrogen and greater than 97% for Total Inorganic Nitrogen. The granular rubber/40% sulfur system continued to improve prior to Day 210, after which Total Nitrogen removal was greater than 90%.

Five day carbonaceous biochemical oxygen demand was < 2 to < 8 mg/L in all three Stage 1 effluents, with removal efficiencies exceeding 94% for all filters. These results verify the ability of the Stage 1 filter designs to remove organic matter in septic tank effluent in addition to nitrogen species. The experimental evaluation verified the potential of the two-stage filter systems for both total nitrogen removal and organics removal using passive technology over an eight month period.

Media Examination

At the conclusion of the study, the two-stage filter systems were disassembled and media samples removed from the filters. The media was subjected to several tests to evaluate changes to media through the 246 day operation. Resident water retention in Stage 1 media was from 19 to 41% of mass and was lowest for larger media particle size. Estimated water detention time in Stage 1 filters was 15 to 48 hours and was highest for expanded clay and lowest for granular rubber. Visual and photographic analysis generally showed no gross accumulation of solids in media materials. The entrance regions of the Stage 2 reactors showed gelatinous accumulation on media surfaces, which is a characteristic of biofilm reactors.

Introduction

As population growth continues in Florida, so do the potential impacts of on-site wastewater treatment systems to surface and groundwater quality. Nitrogen loading from wastewater treatment systems may be a concern where numerous on-site wastewater treatment and disposal systems (OWTS) are located within sensitive environments. Conventional septic tank and soil adsorption systems rely on biological reactions in porous media (unsaturated natural soil or media placed into a treatment zone) to attenuate nitrogen loadings to ground or surface water. Groundwater nitrate concentrations have been shown to exceed drinking water standards by factors of three or greater at distances on the order of several meters from soil adsorption systems. A study at Big Pine Key, Florida found that the dissolved inorganic nitrogen (DIN) levels in groundwater contiguous to on-site drainfields were greater than DIN levels at a control location. Groundwater $\text{NH}_3\text{-N}$ levels at Big Pine Key reached 2.75 millimoles per liter (38.5 mg/L), indicating a high fractional breakthrough of ammonium through the on-site treatment system. In another study, conducted on a sandy Florida aquifer system, groundwater levels of both Total Nitrogen and ammonium were elevated above background levels at a distance of 50 meters from a conventional soil adsorption drainfield. Available setback distances in Florida locations may often be quite limited, which increases the significance of achieving high nitrogen removal percentages within septic tanks, media filters and other in-tank treatment processes, as well as with in soil treatment units. A summary review of a wide variety of on-site treatment approaches showed that systems with some degree of “passive” characteristics exhibited Total Nitrogen removal efficiencies of 40 to 75% and produced effluent TN of 10 to 20 mg/L (Smith et al., 2008). A field study of multiple nitrogen reduction technologies in Big Pine Key, Florida showed that the systems evaluated could provide 70% reductions in Total Nitrogen (TN) but could not reliably produce effluent TN concentrations of less than 10 mg/L (Anderson et al., 1998; Ayres Associates, 2000). FDOH has an interest in exploring the feasibility and practicality of using relatively passive on-site treatment systems to accomplish even higher nitrogen reductions in a cost effective manner.

The mission of the Bureau of Onsite Sewage Programs of the Florida Department of Health (FDOH) is “*Protecting the public health and environment through a comprehensive onsite sewage program*”. FDOH established the Florida Passive Nitrogen Removal Study to identify passive treatment systems that can achieve greater nitrogen reductions than exhibited by conventional septic tank/drainfield configurations. The FDOH is specifically interested in approaches that employ filter media, or reactive filter media, and systems that which eliminate the need for aeration pumps and minimize the need for liquid pumping. The first step of the Florida Passive Nitrogen Removal Study was to identify treatment configurations, reactive and non-reactive media, performance capabilities of new and demonstrated technologies, and factors influencing performance and longevity. The following section describes the results of the literature review and the genesis of the recommended two-stage system for passive nitrogen removal. The experimental evaluation section describes the results of experiments that were performed to verify total nitrogen removal from actual septic tank effluent using passive, two-stage nitrogen removal technology. The economic analysis section presents a detailed life cycle cost analysis of a passive two-stage nitrogen removal system. Finally, the recommendations section provides specific guidance for deployment of passive two-stage nitrogen removal technology for a single family residence.

Approaches to Passive Nitrogen Removal

The overall approach to passive nitrogen removal is a two-stage filter system. The first stage is an unsaturated media filter for ammonification and nitrification. The second stage is a saturated anoxic filter with reactive media (denitrification). This configuration is mandated by the obligatory biochemical sequence of aerobic nitrification followed by anoxic denitrification. The use of an unsaturated media filter for the initial nitrification is necessary because of the constraint that aeration pumps cannot be used in the passive system. The first media filter can be established as a downflow filter, similar to a sand filter for example, and can be connected to the second anoxic denitrification filter that operates in the upflow direction. The flow connectivity between the two filter stages would be by gravity.

The first stage filter must be designed to achieve the targeted final effluent ammonium N levels. Ammonium N may behave conservatively in the anoxic second stage filter, and any additional ammonium N removal in the anoxic filter should be viewed as incidental. The first stage filter will also provide additional processes that will remove biodegradable organics (biochemical oxygen demand) and organic N. Although some denitrification may occur in unsaturated filters that are operated on septic tank effluent (STE) under certain conditions (i.e. simultaneous nitrification/denitrification), the predominant design goal of the first stage filter must be to achieve consistent low levels of ammonium N and organic N. Key factors for first stage media are timed dosing, dosing distribution across the filter surface area, ability to supply oxygen supply by maintaining aeration pore volume, ability to retain water, and adequate space within the media to assimilate suspended solids in the wastewater influent and biomass that is synthesized from degradation of influent wastewater constituents. Unsaturated filter performance is governed by the interaction between the filter media and the manner in which septic tank effluent is imposed onto the media surface. Important factors are the average applied hydraulic and organic loading rates, the timing and volume of dosings, and the distribution of wastewater over the entire surface area of the filter. Review of technologies suggests that ammonium nitrogen reductions of 95% and effluent ammonium N levels of 1 mg/L are possible to achieve. Evaluation of specific filter media, hydraulic and organic loading rates, and water quality must be conducted to define the design parameters needed to achieve low effluent ammonium and organic N concentrations. Promising candidate media include zeolites, expanded clays and shales, tire crumb, peat, coconut coir, and synthetic fiber materials. The first stage unsaturated filter should produce an effluent with low TSS and regrowth potential to minimize potential solids accumulation and channeling in the second stage filter.

The second filter must be designed to achieve the targeted final effluent total oxidized N levels, which are expected to be predominantly in the form of nitrate. Considerations for the second stage media involve surface area per volume, propensity for accumulated suspended solids to reduce hydraulic conductivity (clogging) and lead to preferential flow, and operating factors such as the applied hydraulic and organic loading rates. The need to provide a continuous supply of electron donor for denitrification, and to supply it over extended periods of deployment, is central to the purpose of the reactive media. Review of technologies suggests that it should be possible to achieve effluent nitrate levels of 2 mg/L and less. Evaluation of specific filter media, hydraulic and nitrate loading rates, and water quality must be conducted to identify media and define the design parameters needed to achieve low effluent nitrate concentrations. Candidate

media include elemental sulfur, woodchips, and sawdust; other cost effective materials may also be identified. Literature review suggests two additional considerations that must be addressed for deployment of anoxic reactive media. The first is residuals that are added to water by passage through the reactive media. Wood based materials can add biodegradable organics to water, increasing the chemical and biochemical oxygen demand. Elemental sulfur systems can increase sulfate levels and possibly sulfide. The degree to which residuals are added to the water by the reactive media filters could be reduced by replacing a fraction of the reactive media with inert filler. However, care must be taken to insure continuous electron donor supply over the target deployment period. Thus, anoxic filter systems must be formulated with a sufficient electron donor supply to support denitrification and achieve target nitrate removals, but with as small a release of excess electron donor as is feasible.

A second factor in anoxic filter design is the long term hydraulic performance, which may be even more significant to the longevity of anoxic denitrification filters than the duration of electron donor supply. Preferential flow paths can be initiated through deposition of organic and inorganic solids within the filter media, and by methods used to distribute and withdraw flow into and through the reactive media. Preferential flow paths can lead to channelization, reduced contact with reactive media surfaces, and performance deterioration. The ability to predict a priori the propensity for channelization phenomena is limited, particularly in the anoxic filters, which host biochemically reactive systems with complex water chemistries and which experience a significant transition from a predominantly aerobic to an anoxic redox environment. Approaches to overcoming channelization involve manipulation of media, inlet and outlet arrangements, the provision of a minimum amount of headloss, baffling, the use of long aspect ratio reactors, using large systems that provide acceptable performance over time even with some degree of channelization, or using smaller filters with lower retention times that are changed out more frequently. Continuous deployments of treatment systems over time periods of months and longer are needed to fully examine these factors.

The embodiment of the two-stage treatment system as an in-tank process has advantages over a modified drainfield approach. Achieving acceptably low effluent Total N removals over time periods of many years will require access to filter media for effluent monitoring, media maintenance and change out when required, and verification of desired hydraulic operation. Replacement or maintenance of denitrification media could be accomplished without disturbing the first stage media. The use of the two-stage in-tank process, passively connected hydraulically, would avoid the vagaries inherent in verifying the continuing performance of subsurface flow systems. The second stage saturated filter could be deployed as a horizontal subsurface filter bed as long as it remained saturated.

Experimental Evaluation

Materials and Methods

Project Site

The experimental studies were conducted at Flatwoods Park, 18205 Bruce B. Downs Boulevard, Tampa FL 33592. The park is a day use public recreational facility operated by Hillsborough County. Wastewater is generated by two sources: a lavatory with two hand washing sinks and two flush toilets, and a continuously occupied single family home (ranger residence). The park was open for public use every day during the study period. Park visitation is highest on weekends and on weekday afternoons. Wastewater from the ranger residence and lavatory is collected in a septic tank before being pumped to a mounded onsite sewage and disposal system. The source water for the ranger residence and lavatory is municipal water supplied by the City of Tampa.

Experimental Treatment Systems

The filter media that were evaluated are listed in Table 1, along with the estimated bulk density and the range of particle sizes of the material as procured. Stage 1 media included clinoptilolite, expanded clay and tire crumb, all of which provide substantial external porosity (> 45%). Clinoptilolite and expanded clay would be expected to exhibit higher water retention water characteristics when compared to granular rubber. Additionally, the clinoptilolite media provides cationic ion exchange capacity (1.5 to 1.8 meq./g) which could enhance sorption and retention of ammonium ions. Tire chips are produced by the cutting up of recycled tires, and are available in particles sized of 5 mm and less that are suitable for use as filter media. Details of column design are included in the original Passive Nitrogen Removal Study (Smith et al., 2008).

Clinoptilolite media was obtained by the supplier in three particle size gradations: 16x50, 8x16, and 4x8. The 16x50 was passed through a No. 35 mesh sieve to remove the smaller particles; materials retained on the screen were particles of 0.50 to 1.19 mm size. The 8x16 (1.19 to 2.38 mm) and 4x8 (2.38 to 4.76 mm) sizes were used as supplied. Each clinoptilolite size fraction was rinsed eight times before placement in the filter. Livlite and tire crumb media were prepared using dry sieving as follows. Media were initially sieved through a 5 mm square mesh wire screen to remove extraneous larger particles. Materials passing through the 5 mm screen were sieved through a 3 mm square mesh screen. Materials that were retained on the 3 mm screen composed the 3 to 5 mm size material that was used in the upper layer of the filter. Materials passing through the 3 mm screen were sequentially sieved through US Sieve Numbers 10, 18 and 35 (openings of 2.00, 1.00 and 0.500 mm), providing media of 1.0 to 2.0 mm size for the middle filter layer and 0.5 to 1.0 mm size for the lower filter layer. While filter media can be more completely characterized using particle size distribution analysis (PSD), effective diameter (D_{10}), and uniformity coefficient (D_{60}/D_{10}), these data were not available for the materials as procured nor obtained for the size fractions.

The Stage 2 electron donor media was elemental sulfur, which provided an autotrophic denitrification process in the anoxic filter. Crushed oyster shell was used as an alkalinity source, as sulfur-based autotrophic denitrification will consume alkalinity. Expanded shale was included

in two Stage 2 columns and provided anion exchange capacity, which would sorb nitrate under non-steady operational conditions.

A schematic of the experimental filter columns is shown in Figure 1. Three filter systems were evaluated, each consisting of an unsaturated filter followed by a saturated filter. Filters were fabricated from at 3 in. inner diameter PVC for Stage 1 (unsaturated) filters and 1.5 in. inner diameter PVC for Stage 2 (saturated) filters. A 1/8 inch square mesh screen was used for media support and retention at the outlet media end of each column.

A single peristaltic pump (Cole Parmer) was used to dose septic tank effluent to the three Two-Stage Filter systems. Each Stage 1 filter was dosed with a separate pump head; the three pump heads were attached to the same pump. STE was supplied through a single tube connected to an intake manifold (3 in. PVC pipe) with 1/16 in. slots located in the septic tank. The STE tube branched into three separate tubes prior to the pump heads; each branch tube supplied one peristaltic pump head. The sizes of pump head and pump head tubing, and the pump speed and run time were identical for all three Two-Stage Filter systems.

The media configuration in the six columns is shown in Table 2. Total media depth in the vertical unsaturated Stage 1 columns was 24 in. The Stage 1 filters employed a stratified media configuration, with particle sizes decreasing in the downward direction, with 2 in. of larger particle sized media on the bottom for particle retention. Stratification of media based on particle size was based on the expected progression of biochemical reactions within the filter media. The processes in the upper media layer include adsorption of wastewater particulates and colloids, hydrolysis and release of soluble organics, aerobic utilization of soluble organics, and biomass synthesis. In this region, the biochemical processing of organic matter between doses must keep up with the newly applied wastewater constituents from each dose. The greatest accumulation of organic and inorganic mass will occur in the upper layer, and the use of larger particle size media will provide greater space for accumulation of solids. Stratified media should enhance the potential for long term operation while maintaining treatment efficiency.

Table 1 Procured Filter Media

Material	Bulk density, lb/ft³	Particle Size Range
Zeo-Pure AMZ Clinoptilolite	55	0.3 - 4.76 mm
Livlite Expanded Clay	41	0.4 - > 5 mm
Granular Rubber	25	0.3 - > 5 mm
Elemental sulfur	77	2 - 5 mm
Oyster shell	82	3 - 15 mm
ACT-MX ESF-450 Utelite	54	0.4 - 4.5 mm

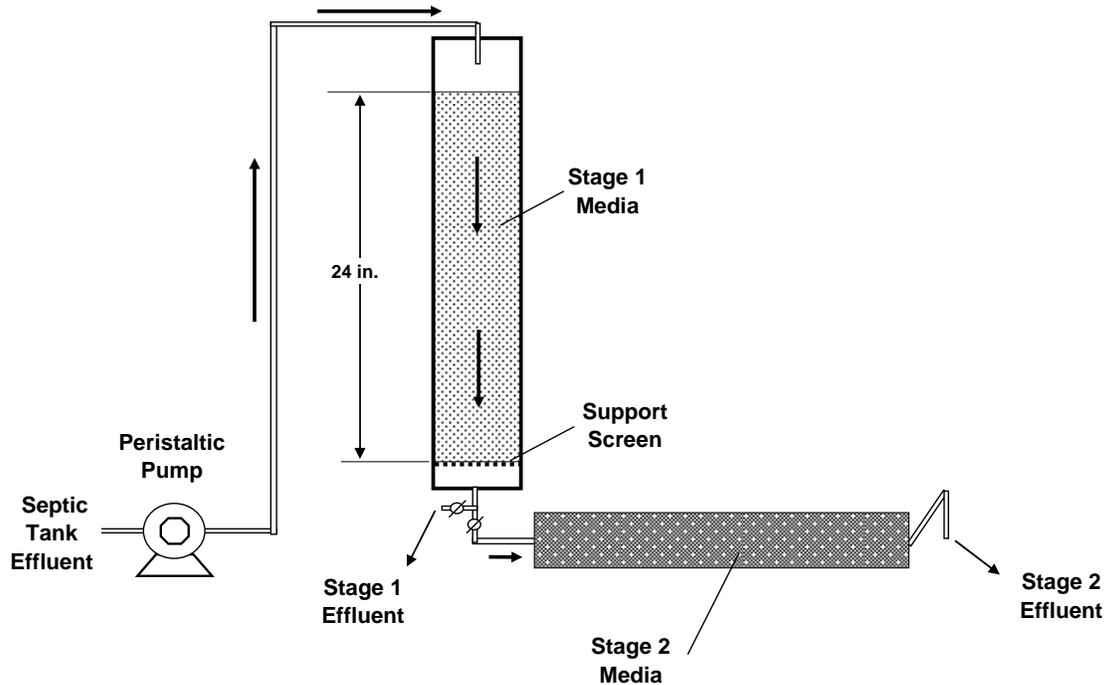


Figure 1 Experimental Filter System Schematic

Three Stage 2 columns were constructed using unstratified media containing elemental sulfur, crushed oyster shell, and expanded shale (Table 2) of 24 in. total media depth. Each filter contained a 3:1 vol./vol. ratio of elemental sulfur to crushed oyster shell. The fraction of expanded shale in Stage 2 media ranged from 0 to 40%. Expanded shale contains anion exchange capacity which can bind nitrate ions, potentially enhancing removal. Higher expanded shale fractions were accompanied by lower elemental sulfur fractions, which would reduce the total surface area of elemental sulfur and possibly the overall sulfur oxidation rate. A lower sulfur oxidation rates could have the positive effect of reducing effluent sulfate levels if sulfur oxidation exceeded the amount needed for denitrification.

The Stage 1 filters were vertically oriented and Stage 2 filters oriented horizontally (Figure 1). The Stage 1 filters were supplied with septic tank effluent by a multi-head peristaltic pump with a timed dosing of once per one half hour (48 doses/day). Wastewater trickled downward through the Stage 1 media, through the support screen, and into a tube that directed Stage 1 effluent to the Stage 2 filter (Figure 1). The water elevation in the tube below the Stage 1 filter provided hydraulic head for passive movement of water through the Stage 2 filter. A valve and sample port (with another valve) was located in the tube below the Stage 1 filter. In normal filter operation, the sample port valve was closed and the valve leading to Stage 2 open, providing passive flow of Stage 1 effluent to and through the horizontal Stage 2 filter. The design of the two-stage filter system minimized internal volume within the connecting piping; liquid volumes in the Stage 1 and Stage 2 filters comprised greater than 90% of the total internal volume.

Operation and Monitoring

Operation of the experimental treatment systems under the original study was commenced on 1/2/2008. The original study was completed on 3/2/2008, but operation was continued in an identical manner through 9/3/2008. The target hydraulic loading rate to the Stage 1 filters was 3 gallons of septic tank effluent per square foot of surface area per day. The additional sampling events presented in this report were conducted operation Days 123, 152, 196, 208 and 245.

Monitoring was conducted at seven monitoring points, consisting of influent septic tank effluent (STE), effluents from each Stage 1 filter, and effluents from each Stage 2 filter. Temperature, pH, and dissolved oxygen (DO) measurements were performed by inserting probes directly into the Stage 2 effluent port, into Stage 1 effluent collection reservoirs, and for STE in a 1 liter sample container immediately after collection. Sulfate and nitrogen samples from the effluents of Stage 1 and Stage 2 filters were collected by routing effluent from the filters directly into prepared sample containers located in an iced cooler. For STE, samples for sulfate, nitrogen, biochemical oxygen demand (BOD), and total suspended solids (TSS) were collected by directly filling prepared sample containers with pumped STE and immediately placing samples containers on ice in a cooler.

In the additional monitoring study, monitoring was generally conducted in the following sequence:

- Stage 2 effluent: temperature, pH, DO, alkalinity
- Stage 2 effluent: nitrogen sample collection
- Stage 1 effluent: nitrogen sample collection
- STE: nitrogen sample collection
- STE: BOD sample collection
- Stage 1 effluent: BOD sample collection
- STE and Stage 1 effluent: temperature, pH, DO, alkalinity

Analytical Methods

Nitrogen and C-BOD₅ analyses were performed by a NELAC certified laboratory (ELAB Inc.). Total kjeldahl nitrogen was performed by digestion and colorimetric determination (EPA 351.2). Ammonium nitrogen was performed by semi-automated colorimetry (EPA 350.1). Nitrate plus nitrite nitrogen was performed by cadmium reduction and colorimetry (EPA 353.2). Sulfate was measured by anion chromatography (EPA 300.0). Quality assurance and control procedures were followed by ELAB Inc.

Temperature, pH and dissolved oxygen (DO) were measured using a Hach 40d multimeter with Intellical glass membrane probe and luminescent Dissolved Oxygen probe. Probes were calibrated according to manufacturer's instructions using three standard solutions (4,7,10) for pH, and for DO, an air saturated water solution and a zero DO (sodium sulfide) solution. The Hach LDO probe (LDO 10103) included a temperature sensor that performed automatic temperature compensation for DO. Total alkalinity was measured by titration with 1.6N sulfuric acid to a bromocresol green-methyl red endpoint.

Table 2 Configuration of Two-Stage Filter Media

Stage	Filter	Column inner diameter, inch	Media depth, inch	Media placement	Media				
Stage 1 unsaturated aerobic	1A	3.0	24.0	Stratified	Clinoptilolite depth (in.) diameter (mm) top 8 2.38 - 4.76 8 1.19 - 2.38 6 0.5 - 1.19 1 1.19 - 2.38 1 2.38 - 4.76 bottom				
					Expanded Clay depth (in.) diameter (mm) top 8 3 - 5 8 1.0 - 2.0 6 0.5 - 1.0 1 1.0 - 2.0 1 3 - 5 bottom				
					Granular Rubber depth (in.) diameter (mm) top 8 3 - 5 8 1.0 - 2.0 6 0.5 - 1.0 1 1.0 - 2.0 1 3 - 5 bottom				
	1B				1.5	24.0	Nonstratified (1 - 3 mm)	75% elemental sulfur 25% oyster shell	
								60% elemental sulfur 20% oyster shell 20% expanded shale	
								45% elemental sulfur 15% oyster shell 40% expanded shale	
	1C				2A	1.5	24.0	Nonstratified (1 - 3 mm)	75% elemental sulfur 25% oyster shell
									60% elemental sulfur 20% oyster shell 20% expanded shale
									45% elemental sulfur 15% oyster shell 40% expanded shale

Results and Discussion

Applied Hydraulic Loading

Applied hydraulic loadings to Stage 1 filters for the additional monitoring period (Day 123 to 246) are summarized in Table 3. Flowrates were measured by collecting and quantifying the cumulative liquid volume exiting the Stage 2 filters (i.e. the final effluent) over time periods of 15 to 40 hours and dividing volume by elapsed time. Hydraulic loading rates over the time of experimental operation are shown in Figure 2. Flowrates were fairly consistent and average hydraulic loading rates were within 10% of the target of 3 gal/ft²-day to Stage 1 filters.

Table 3 Applied Hydraulic Loading Rate (n=18)

System	Media	Average (gal/ft ² -day)	Standard Deviation (gal/ft ² -day)
1	Clinoptilolite / 75% Sulfur	2.82	0.21
2	Expanded clay / 60% Sulfur	2.96	0.37
3	Tire crumb / 45% Sulfur	2.83	0.33

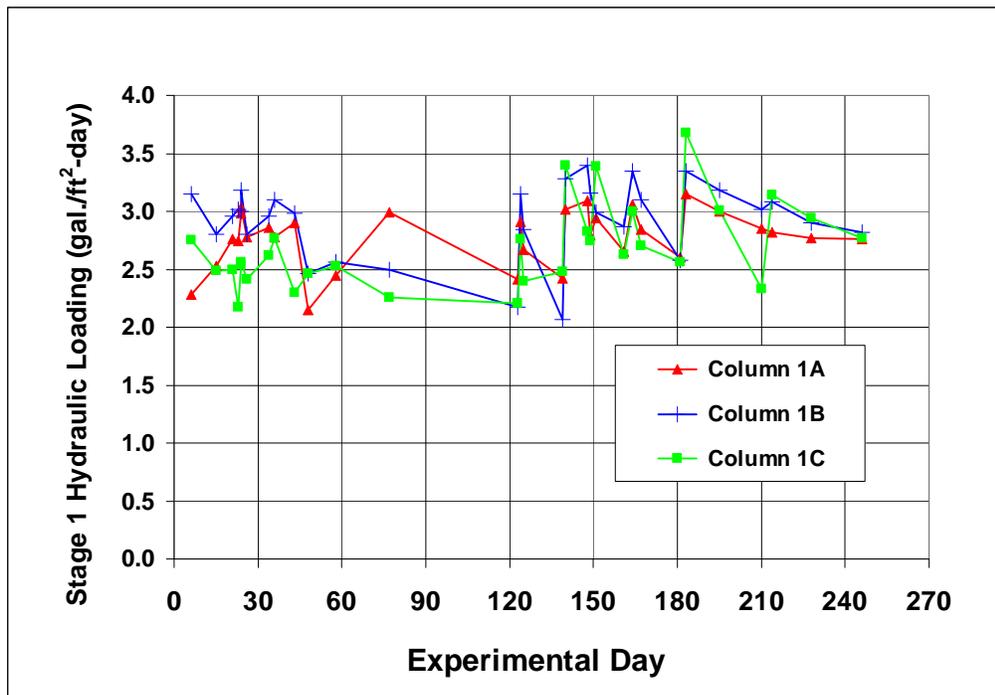


Figure 2 Hydraulic Loading Rate Applied to Stage 1 Filters

Septic Tank Effluent

Septic tank water quality parameters for the additional monitoring period (Day 123 to 246) are summarized in Table 4. The average Total Nitrogen (TN) of 66.9 mg/L was somewhat higher than typical for single family residences and may reflect the contribution of day users to the wastewater. The majority of STE nitrogen was TKN and dominated by ammonium as is characteristic of single family residence STE.

Table 4 Septic Tank Effluent Quality
 (n=5; all values in mg/L except pH)

Component	Average	Standard Deviation	Range
Total Nitrogen	66.9	21.0	50 - 98
Organic Nitrogen	8.4	3.3	4 - 13
NH ₃ -N	58.4	20.5	41 - 91
NO _x -N	0.09	0.10	.025 - .25
DO	0.022	0.004	.01 - .03
pH	7.34	0.24	7.12 - 7.69
Alkalinity	526	37	469 - 569

Applied Nitrogen Loading

Applied loading of Total Nitrogen (TN) is shown in Figure 3. The variations in loading with time reflect both the variations in hydraulic loading rate and variation in STE TN. The applied nitrogen loading varied between 6 and 12 grams per square meter of Stage 1 filter surface area per day and was lower from Day 179 to 245 because of lower STE TN.

Performance of Two-Stage Treatment Systems

Nitrogen species in the influents and effluents of each filter in the two-stage systems are summarized in Table 5 and removal efficiencies are summarized in Table 6. Total nitrogen concentrations of the two-stage filter systems are presented in Figure 4. Average TN removal efficiency of Systems 1 and 2 were 96.8 and 95.1%, respectively, with average effluent TN of 2.2 and 3.2 mg/L. System 3 average effluent TN was significantly higher than Systems 1 and 2, reflecting the decreasing effluent TN pattern prior to Day 210 (Figure 4). Lower ammonium removal in the Stage 1 filter and nitrate removal both contributed to lower TN removal efficiencies in System 3 prior to Day 210.

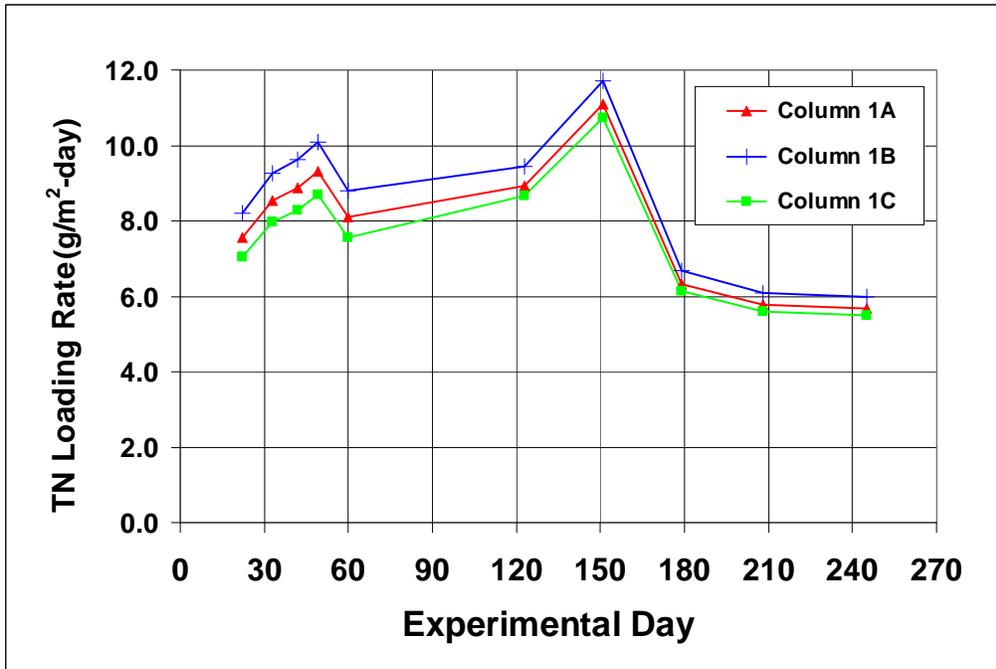


Figure 3 Areal Nitrogen Application Rate to Stage 1 Filters

Table 5 Nitrogen Species In Filter Influent and Effluents
 (Days 123 to 245; Average of n=5; all values in mg/L)

Sample Point	Total Nitrogen	Organic N	NH ₃ -N	NO _x -N	Total Inorganic Nitrogen
Influent (STE)	66.9	8.4	58.4	0.090	58.5
Stage 1 Effluent					
1A Clinoptilolite	52.0	0.72	0.028	51.2	51.2
1B Expanded clay	63.2	0.39	0.17	62.6	62.8
1C Granular rubber	67.8	4.6	4.2	59.0	63.1
Stage 2 Effluent					
2A 75% Sulfur	2.2	1.6	0.50	0.032	0.53
2B 60% Sulfur	3.2	1.9	1.3	0.041	1.3
2C 45% Sulfur	10.4	4.3	4.8	1.3	6.1

Table 6 Two-Stage Treatment System Nitrogen Removal Efficiency
 (Days 123 to 245; Average of n=5)

System	Media	Total Nitrogen Reduction (%)		Total Inorganic Nitrogen Reduction (%)	
		Average	Range	Average	Range
1	Clinoptilolite / 75% S	96.8	95 - 97.8	99.2	98.6 - 99.6
2	Expanded Clay / 60% S	95.1	93.7 - 96.7	97.0	96 - 97.9
3	Granular Rubber / 45% S	86.6	74.5 - 93.6	92.2	79.4 - 98.6

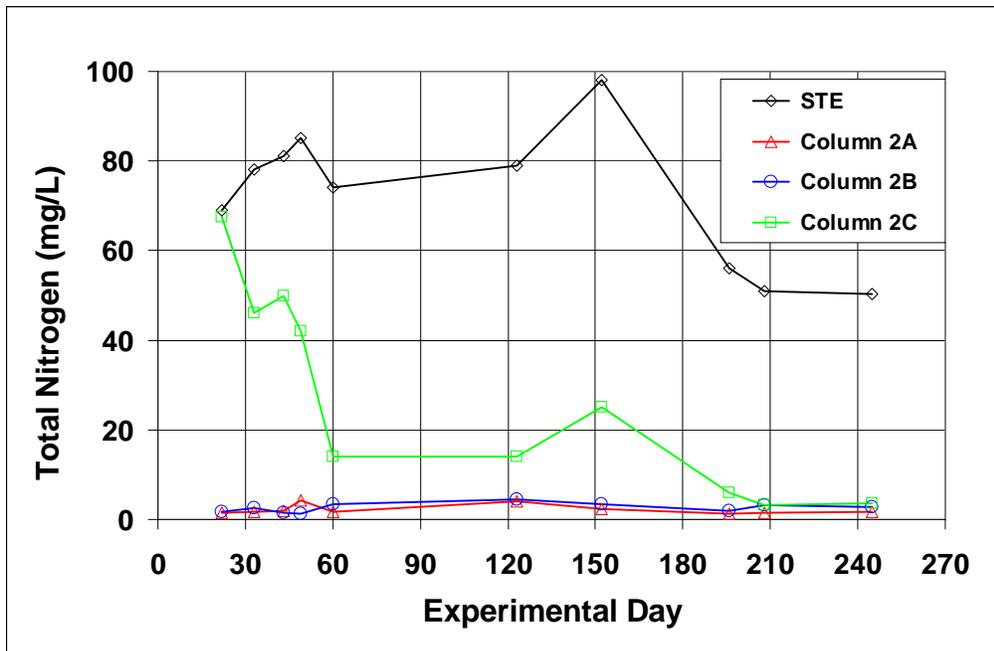


Figure 4 Total Nitrogen in Influent STE and Effluent of Two-Stage Filter Systems

Performance of Unsaturated Aerobic Filters (Stage 1)

Ammonium nitrogen levels in effluent from the unsaturated Stage 1 filters are shown in Figure 5. The high ammonium nitrogen reductions observed in the clinoptilolite and expanded clay filters continued throughout the study until Day 245. In the granular rubber filter, ammonium appeared to reach a steady level after Day 210. Stage 1 ammonium removal efficiency on a highly expanded scale is shown in Figure 6. The clinoptilolite (Column 1A) and expanded clay (Column 1B) filters consistently removed greater than 99% ammonium, while the ammonium removal efficiency with granular rubber media reached a similar level after Day 210.

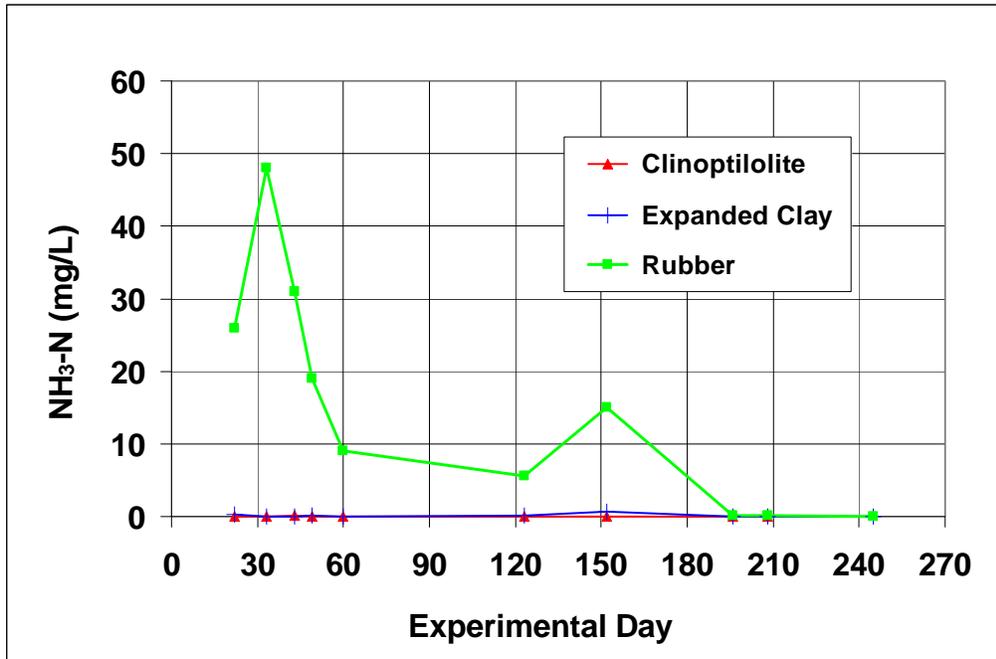


Figure 5 Effluent Ammonium from Unsaturated (Stage 1) Filters

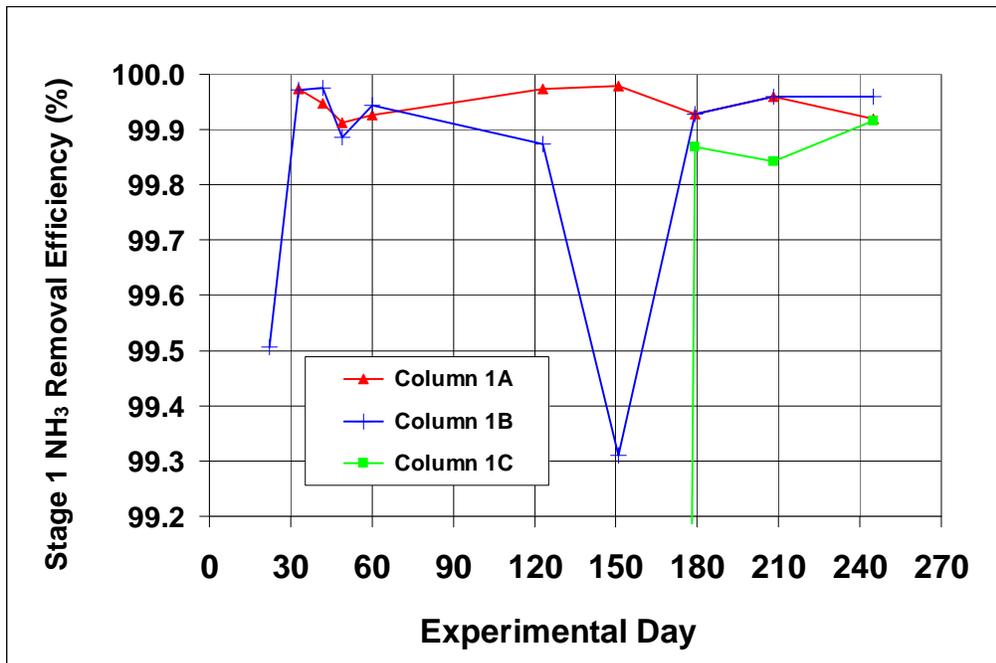


Figure 6 Stage 1 Ammonium Removal Efficiency

Performance of Anoxic Denitrification Filters (Stage 2)

The performance of the three denitrification (Stage 2) filters is illustrated in Figures 7 and 8. NO_x concentrations were quite low and TIN removal efficiencies high for System 1 (clinoptilolite / 75% sulfur) and System 2 (expanded clay/ 60% sulfur) throughout the study. System 3 (granular rubber/ 40% sulfur) showed less complete NO_x removal through Day 210.

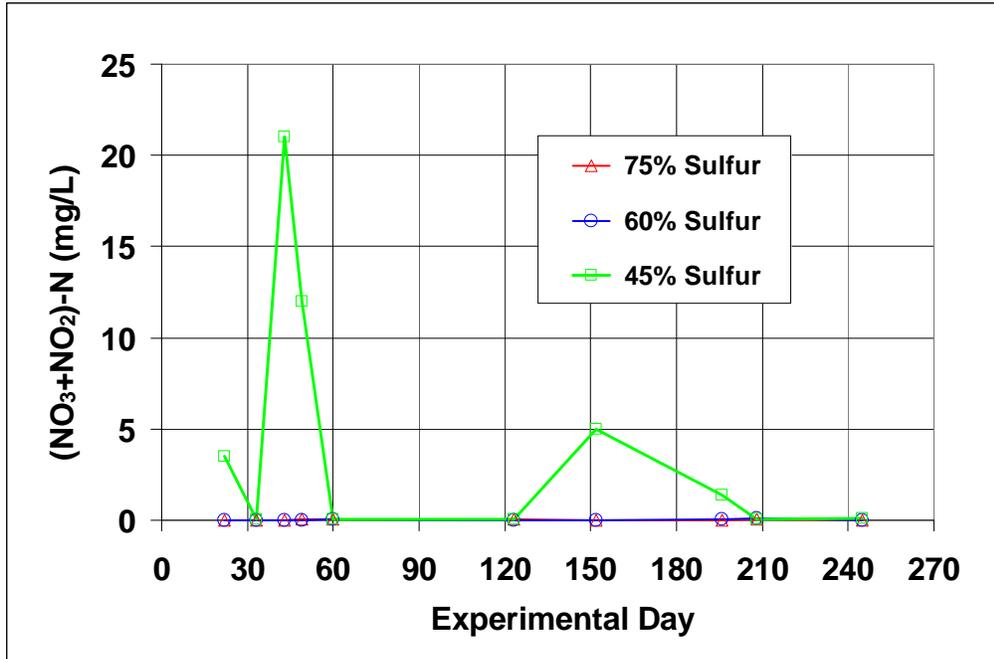


Figure 7 NO_x Concentrations in Stage 2 Filter Effluents

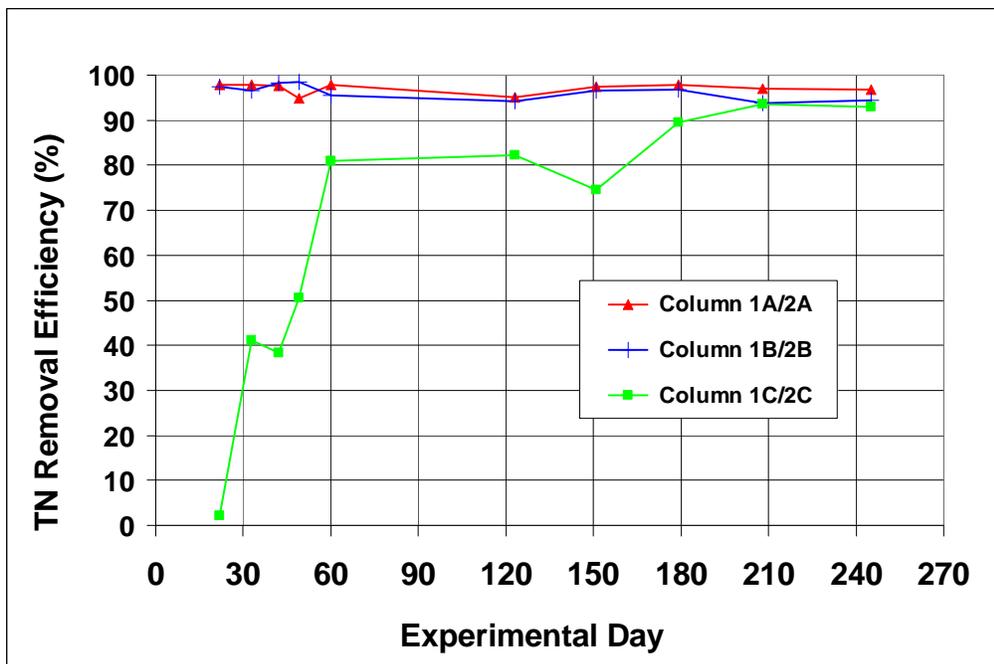


Figure 8 Total Nitrogen Removal Efficiencies of Two-Stage Filters

Carbonaceous Biochemical Oxygen Demand

The removal of five day carbonaceous biochemical oxygen demand (C-BOD₅) was evaluated in three sampling events during which C-BOD₅ was analyzed in septic tank effluent and the effluents of the Stage 1 filters. The results are shown in Table 7. STE C-BOD₅ ranged from 120 to 160 mg/L and ranged from < 2 to < 8 for all three columns. The less than designations in the reported results reflect the different dilutions that were applied on the different sampling events days. C-BOD₅ removal efficiency ranged from > 94 to > 98% for all three Stage 1 columns. Based on ammonium removal performance of the Stage 1 filters that was found in the initial 60 day study, a high removal of for C-BOD₅ was presumed but not demonstrated. The results shown in Table 7 verified the expectation that C-BOD₅ removal efficiency would be high.

Table 7 Carbonaceous Biochemical Oxygen Demand in STE and Stage 1 Effluents

Date	Effluent C-BOD ₅ , mg/L			
	Septic Tank	Clinoptilolite	Expanded Clay	Granular Rubber
5/4/2008	130	< 8	< 8	< 8
6/3/2008	160	4.0	3.5	8.4
7/2/2008	120	< 2	< 2	< 2
% Removal Efficiency	-	> 94, 98, > 98	> 94, 98, > 98	> 94, 95, > 98

Field monitoring parameters are listed in Table 8 and summarized in Table 9. Each of the three Stage 1 media was effective in increasing dissolved oxygen (DO) from virtually zero in STE to typically 6 mg/l or greater (Figure 9). While wastewater DO was increased significantly by passage through the unsaturated Stage 1 filters, it was reduced significantly by passage through Stage 2 filters; Stage 2 effluent DO was consistently less than 0.5 mg/L with the exception of Column 2C (Figure 10).

Inspection of the data in Table 8 indicated that the pH of Stage 1 effluent as lower than that of STE. The decline in pH through Stage 1 treatment appears to be associated with the process of biochemical nitrification. Ammonia was significantly reduced in Stage 1 filters throughout the study, Nitrification consumes 4.57 mg/l alkalinity as CaCO₃ per gram ammonium nitrogen nitrified.

Table 8 Field Parameters in Influent and Filter Effluents

May 4/5 2008		Temp C	DO mg/L	pH	Alkalinity
Influent		31.2	0.02	7.69	469
Stage 1	System 1	30.5	5.75	5.75	300
	System 2	30.1	6.39	6.72	63
	System 3	30.5	0.73	6.00	69
Stage 2	System 1	21.6	0.08	6.72	369
	System 2	21.6	0.08	6.68	300
	System 3	22.2	0.05	6.68	313
June 2 2008		Temp C	DO mg/L	pH	Alkalinity
Influent		25.4	0.03	7.12	569
Stage 1	System 1	31.8	6.73	7.05	178
	System 2	32.1	5.35	5.69	38
	System 3	33.6	3.08	5.43	25
Stage 2	System 1	22.4	0.06	6.70	394
	System 2	22.6	0.04	6.45	244
	System 3	23.3	0.18	6.30	219
July 1 2008		Temp C	DO mg/L	pH	Alkalinity
Influent		31.9	0.03	7.13	519
Stage 1	System 1	29.9	6.76	7.21	113
	System 2	30.7	6.60	5.51	44
	System 3	29.9	6.06	5.83	44
Stage 2	System 1	23.4	0.08	6.76	363
	System 2	23.4	0.06	6.70	250
	System 3	23.9	0.28	6.39	144
July 28/29 2008		Temp C	DO mg/L	pH	Alkalinity
Influent		33.8	0.01	7.44	544
Stage 1	System 1	27.9	7.71	7.18	119
	System 2	27.9	7.33	7.33	50
	System 3	27.9	6.93	6.93	75
Stage 2	System 1	33.1	0.07	6.84	369
	System 2	33.6	0.08	6.71	238
	System 3	32.9	0.07	6.62	144
September 3 2008		Temp C	DO mg/L	pH	Alkalinity
Influent		32.3	0.02	7.33	531
Stage 1	System 1	28.2	7.54	7.21	113
	System 2	27.7	7.57	6.88	81
	System 3	27.5	7.52	6.64	75
Stage 2	System 1	24.4	0.03	6.89	369
	System 2	24.5	0.04	6.82	238
	System 3	24.7	0.04	6.77	144

Table 9 Average Field Parameter Values for Days 123 to 245
 (n=5)

Sample Point	Dissolved Oxygen, mg/L	pH	Alkalinity, mg/L as CaCO ₃	Alkalinity Change, mg/L as CaCO ₃
Influent (STE)	0.02	7.34	526	-
Stage 1				
1A Clinoptilolite	6.92	6.97	164	- 362
1B Expanded clay	6.65	6.31	55	- 471
1C Granular rubber	4.86	6.24	58	- 469
Stage 2				
2A 75% Sulfur	0.06	6.78	370	+ 206
2B 60% Sulfur	0.06	6.67	265	+ 210
2C 45% Sulfur	0.12	6.55	205	+ 148

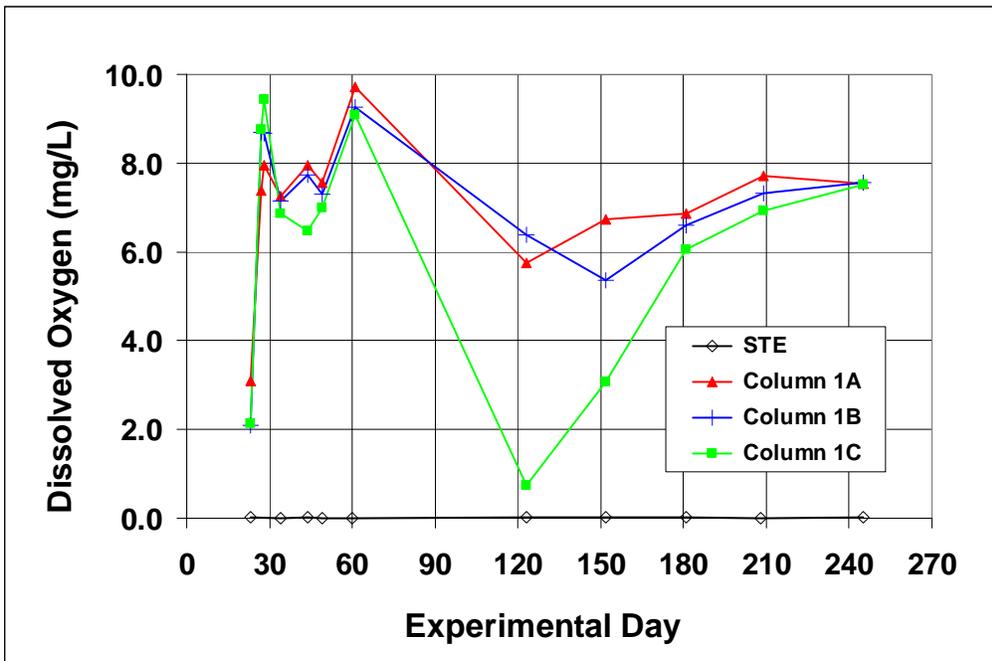


Figure 9 Dissolved Oxygen in Effluent of Unsaturated Filters (Stage 1)

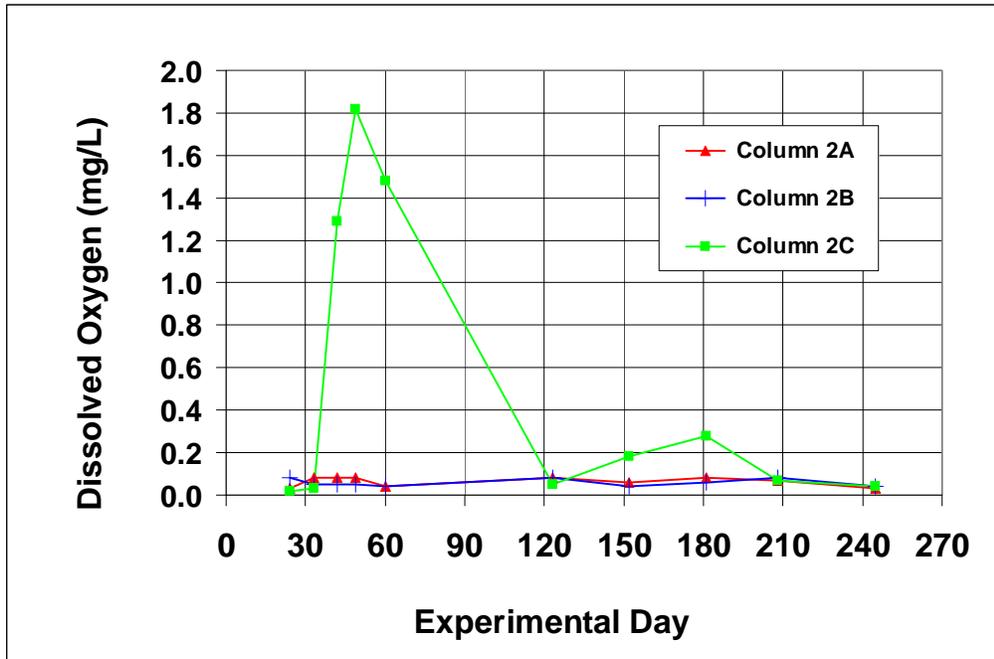


Figure 10 Dissolved Oxygen in Effluent of Denitrification Filters (Stage 2)

Statistical Tests

Statistical tests were performed to compare STE composition and two-stage filter performance for the additional monitoring events (Period 1, Day 22 to 62) with the original PNRS study (Period 2, Day 123 to 245). Additional statistical tests were performed to compare the performance of the three filter systems to each other during Period 2. The central focus was on BOD and nitrogen levels in STE and nitrogen levels in filter effluents.

A comparison of STE composition between Period 1 (Day 22 to 62) and Period 2 (Days 123 to 245) is presented in Table 10. The two data sets for C-BOD₅ and for TN were both compared using the unpaired t-test, since all were normally distributed with equal variance. Although mean STE C-BOD₅ in Period 2 was 1/3 lower than in Period 1, the difference was not significant statistically, reflecting the limited number of analyses in each data set. Mean STE TN in Period 2 was 14% lower than in Period 1, but was also not statistically significant.

A comparison of effluent nitrogen concentrations between Period 1 and Period 2 is shown in Table 11. For each comparison, the unpaired t-test was performed when the statistical criteria for normal distribution and equal variance were met by both data sets; otherwise, the Mann Whitney rank sum test was employed. For Systems 1 and 2, the final effluent (Stage 2) TN in Period 2 was not significantly different than in Period 1, effluent TN was significantly lower for System 3. This was due to the improvement in performance in System 3 prior to Day 210. For Systems 1 and 2, both Stage 1 effluent ammonium and Stage 2 effluent NO_x in Period 2 were not significantly different than in Period 1. The removal of ammonium in Stage 1 filters and removal of NO_x in Stage 2 filters are central operative features of Passive Nitrogen Removal Systems. The effluent concentrations of ammonium and NO_x in Phase 1 and Phase 1 (Table 11)

indicate that these key passive nitrogen removal features continued successfully through eight months of operation. Significant performance differences between Period 1 and Period 2 did obtain for System 3 (granular rubber/45%S) for TN, TIN, and ammonium, reflecting the performance improvement in System 3 that occurred in the period leading up to Day 210. Stage 2 TIN in Period 2 was higher for both Systems 1 and 2, and statistically significant for System 1 even though Period 2 TIN in system 1 was lower than for System 2. The reason for this is an increase in ammonium nitrogen through the Stage 2 columns, which is greater in Period 2 than in Period 1. A possible contributing factor is an increase in microbial biomass and endogenous respiration in the Stage 2 filters, which could lead to the release of ammonium.

A comparison of effluent nitrogen concentrations of the three two-stage filter systems during Period 2 (Days 123 to 245) is shown in Table 12. The Kruskal-Wallis rank sum test was employed for comparison of the effluent nitrogen data sets. Statistically significant differences were found among the three systems for Total Nitrogen and NO_x, and were subsequently determined to be due to the higher levels in System 3.

Table 10. Septic Tank Effluent: Statistical Comparison between Periods 1 and 2

Analyte	Average (mg/L)		Statically Significant Difference
	Period 1	Period 2	Yes / No
C-BOD ₅	203	137	No (T)
Total Nitrogen	77.4	66.9	No (T)

Period 1: Day 22 - 62
 Period 2: Day 123 - 245
 T: Unpaired t-test (α=0.05)

Table 11 Effluent Nitrogen: Statistical Comparison between Periods 1 and 2

Effluent Source/ Analyte	System 1 Clinoptilolite 60% Sulfur			System 2 Expanded Clay 75% Sulfur			System 3 Granular Rubber 45% Sulfur		
	Average N (mg/L)		Statically Significant Difference	Average N (mg/L)		Statically Significant Difference	Average N (mg/L)		Statically Significant Difference
	Period 1	Period 2		Period 1	Period 2		Period 1	Period 2	
Stage 2 TN	2.2	2.2	No (M)	2.1	3.2	No (T)	43.9	10.4	Yes (T)
Stage 2 TIN	0.14	0.53	Yes (T)	0.63	1.29	No (M)	42.1	6.1	Yes (M)
Stage 1 NH ₃ -N	0.047	0.028	No (T)	0.082	0.172	No (W)	26.6	4.2	Yes (T)
Stage 2 NO _x -N	0.027	0.032	No (M)	0.021	0.041	No (M)	7.3	1.3	No (T)

Period 1: Day 22 - 62
 Period 2: Day 123 - 245
 T: Unpaired t-test (α=0.05)
 M: Mann Whitney rank sum test (P=0.05)

Table 12 Statistical Comparison of Two-Stage Filter Effluent Nitrogen for Period 2

Analysis	Clinoptilolite 60% Sulfur	Expanded Clay 75% Sulfur	Granular Rubber 45% Sulfur	Statically Significant Difference
Total Nitrogen	2.2	3.2	10.4	Yes (K)
Total Inorganic Nitrogen	0.53	1.29	6.1	No (K)
Stage 1 NH ₃ -N	0.028	0.172	4.2	No (K)
Stage 2 NO _x -N	0.032	0.041	1.3	Yes (K)

K: Kruskal-Wallis One Way Analysis of Variance on Ranks

Media Examination

Disassembly of Columns and Subsample Collection

Filter columns were removed from the column field assembly and transported to the laboratory. The filters and media were maintained as intact units, with Stage 1 filter columns in vertical position and Stage 2 columns in horizontal position and saturated with water. Stage 1 media was removed by inverting each column and dispensing media onto a clean polyethylene sheet while moving the column along a straight line. The procedure resulted in a line of media approximately two feet long, in which the media was deposited in positions corresponding to depths in the filter columns. Stage 1 filter subsamples were collected at locations corresponding to depths of approximately 2, 12 and 19 in. depth from each column. For each column, after the three subsamples were collected, a portion was placed into pre-tared aluminum pans for gravimetric analysis and the remainder was set aside for visual observation and photographic recording. The Stage 1 sampling procedure was completed approximately 2 hours after the STE flow to the columns was terminated.

The Stage 2 media samples were then collected. End covers were removed and the columns placed in a vertical position to drain pore water. Media samples were then collected at three locations, in order of 3, 12 and 19 in. from the entrance to the media zone. Media samples were collected by cutting open the column at the target sample location and collecting approximately 2 in. of media in prepared beakers. Media subsamples were removed for gravimetric analysis, and the balance set aside for visual observation and photographic recording. The Stage 2 sampling procedure was completed approximately 3.5 hours after the STE flow to the columns was terminated.

Observations of Filter Media

The media was visually observed and photographic images were taken. Stage 1 media at the termination of the study are shown in Figures 11 to 18. The surface of the Stage 1 filters, looking directly down onto media surfaces on Day 246, is shown in Figures 11 through 13. Gross solids accumulation at the media surface was not observable, suggesting that oxidative biochemical processes were able to assimilate influent organic materials over the 246 day period of operation. Samples of media removed from the upper 2 inch layer of each Stage 1 filter are shown in Figures 14 to 16. These photographs show media that contained water and accumulated solids. After eight months of receiving septic tank effluent, the general shape and appearance of the media was observable and the surface shape of the unused media was preserved. In Figure 17 is shown a visual comparison of clinoptilolite media between new media (left) and media from the upper two inches of Column 1A that was dried at 103C. Although the 246 day deployment had darkened the appearance of the clinoptilolite surface, surface shape features were still visible. Organic matter accumulation on media surfaces is an expected feature of biofilm reactors, and drying at 103C would not remove accumulated organic matter. In Figure 18 are shown Stage 1 media samples from the upper 2 in. of the filter column after drying at 103C. All media shown details of geometry and illustrate no gross solids accumulation that masks surface features.



Figure 11 Surface of Clinoptilolite Filter (Day 246).



Figure 12 Surface of Expanded Clay Filter (Day 246).



Figure 13 Surface of Granular Rubber Filter (Day 246).



Figure 14 Clinoptilolite Media from Upper Layer (Day 246).



Figure 15 Expanded Clay Media from Upper Layer (Day 246).



Figure 16 Granular Rubber Media from Upper Layer (Day 246).



Figure 17 Clinoptilolite: New (left) and Column 1A Upper Layer Dried at 103C (Day 246)



**Figure 18 Stage 1 Media, Upper Layer Dried at 103C (Day 246).
Left to right: clinoptilolite, expanded clay, granular rubber.**

Stage 2 media surfaces at the termination of the study are shown in Figures 19 to 21. A cutaway section of Column 2A at 21 in. from the entrance is shown in Figure 19. There was no observable material accumulation on the media or within the column at that location. The white material in Figure 19 was shavings that resulted from the cutting of the pipe. Sulfur media in Figure 19 appeared similar to that of new sulfur media that was placed into all of the Stage 2 columns before startup. For all three Stage 2 columns, sulfur media from the column midsection samples and the samples located downstream towards the outlet end had an appearance similar to new unused sulfur media.

In Figure 20 is shown media from the entrance region of Column 2A after 8 months of operation. This was media as it appeared before drying. In Figure 20, the right side was media nearer the entrance while the left side was farther from the entrance. Inspection reveals what appears to be a gelatinous coating of media near the entrance, which is less pronounced farther from the entrance (i.e. to left in photo). The “slime layer” was also observed in the other Stage 2 columns, but only near the entrance regions; it is a characteristic feature of biofilm reactors operating under certain conditions. The gelatinous material at the head end of the Stage 2 filters suggests that the entrance region of the Stage 2 columns was the site of active microbial processes. Photographs of Stage 2 media after drying at 103C are shown in Figure 21. After drying, the Stage 2 media showed a less observable difference with position in the filters, which can be partially attributed to the high water composition of the ‘slime layer’. After drying at 103C, the

entrance region samples were still darker in appearance. The media from Columns 2B and 2C also showed a generally darker appearance than media from Column 2A due to the increasing percentage of expanded shale.

The mass of sulfur needed to denitrify the total NO_x supplied to each Stage 2 column over 246 days of operation was estimated using the total wastewater volumes and nitrogen concentrations applied to the filters and stoichiometric relationships for sulfur based autotrophic denitrification. The resulting fractional consumptions of sulfur for Columns 2A, 2B and 2C were 1.8, 3.5 and 3.5, respectively, corresponding to longevities of 19 to 39 years.



Figure 19 Filter 2A, 21 in. (Day 246).



Figure 20 Filter 2A, 2 in. (Day 246).



**Figure 21 Stage 2 Media Dried at 103C (Day 246).
Left to right, Column 2A, 2B, 2C.
Top to bottom in direction of column entrance to exit.**

Gravimetric Analysis

Gravimetric analyses were conducted to provide measurements of water in the filter media (Table 13). Stage 1 media samples from 2, 12 and 19 in. locations corresponded to large, medium and small media particle sizes (Table 2). In the Stage 2 columns, the samples from 3, 12 and 19 in. locations represented media near the inlet, midpoint, and downstream section of the filter column. Water content for Stage 1 media are expressed as percent of the total mass of media sample (solids + water); the % water content depends on the dry bulk density of the media. On this basis, the water content was similar for clinoptilolite and granular rubber, and higher for expanded clay. For all three media, water fraction was lowest for the large particle size media located at the top of the filter. For Stage 2 media, water content was lowest for the column with the greatest sulfur content. The 60 and 45% sulfur filters contained expanded shale, which may have contributed to higher water content by the lower bulk density and higher water retention of expanded shale media.

The water content data were used along with dry bulk density of media and filter empty bed volume to estimate the mass of resident water within each of the Stage 1 filters (Table 14). The expanded clay media had the highest calculated water mass and the granular rubber the lowest. The average retention time of water within the Stage 1 columns, calculated using 3 gal/ft²-day areal loading, was lowest for granular rubber (15.3 hr) and highest for expanded clay (48 hr.). These results provide some consistency with the concept, elucidated in the PNRS literature review, that superior performance can be provided by unsaturated media filters that employ high water retention media. A calculation of water layer thickness on the media surface was made by assuming uniform film thickness and idealized spherical particle geometry. Results provided

water layer thicknesses of 37 to 350 μm . This theoretical result is limited and does not account for water contained within internal pores in the media and held between particles by capillary forces.

Biofiltration is conducted by microbial biofilms that colonize media surfaces. To estimate organic matter (OM) content, the Stage 1 media samples that were used for the analysis of water content were also subject to combustion at 500 to 600C. OM analysis by combustion was not possible for filters containing granular rubber and elemental sulfur (i.e. all Stage 2 filters) because the combustion temperature for OM analysis exceeds the temperature of vaporization of synthetic rubber and elemental sulfur. Organic matter as a fraction of the total dry mass of filter media (which includes dry biomass) was 1.8 to 2.3% in three samples of clinoptilolite media, and 0.3 and 1.6% in two samples of expanded clay media (Table 15). Organic matter on filter media includes actively metabolizing biomass, organic products of endogenous decay, microbial exudates such as polysaccharides and other constituents forming a “slime layer”, and particulate and colloidal organic materials from STE wastewater that are retained on the filter media through straining, sedimentation, and Brownian diffusion. Theoretical calculations based on the measured OM fractions suggest that the accrued organic material would form a thickness of 10 to 150 μm if present as films of uniform thickness on idealized spherical particles. Although the number of OM results was limited, they indicate that organic matter accumulation within unsaturated filter media was not excessive after eight months of operation.

Table 13 Gravimetric Analysis of Filter Media

Filter	Media	Distance from Entrance (in.)	% Solids	% Water
Stage 1	clinoptilolite	2	80.8	19.2
		12	75.5	24.5
		19	76.7	23.3
	expanded clay	2	64.5	35.5
		12	61.1	38.9
		19	59.1	40.9
	granular rubber	2	80.7	19.3
		12	75.9	24.1
		19	69.4	30.6
Stage 2	75% S	3	90.4	9.6
		12	91.9	8.1
		19	89.2	10.8
	60% S	3	78.4	21.6
		12	86.7	13.3
		19	87.7	12.3
	45% S	3	83.4	16.6
		12	83.1	16.9
		19	84.2	15.8

Table 14 Derived Residence Time in Stage 1 Filters

Stage 1 Media	Mass Resident Water (gram)	Water Retention Time (hour)
clinoptilolite	704	30.3
expanded clay	1,131	48.7
granular rubber	355	15.3

Table 15 Organic Matter in Stage 1 Filter Media

Stage 1 Media	Distance from Media Entrance (in.)	Organic mass/dry mass (gram/gram)
clinoptilolite	2	0.018
	12	0.023
	19	0.020
expanded clay	2	0.016
	12	0.003

Electron Microbeam/Electron Dispersive Spectrometry

Samples of fresh, unused media and of media removed from the two-stage filters on Day 246 were collected, packaged, and shipped to the Florida Center for Analytical Electron Microscopy at Florida International University in Miami, Florida. Samples were subjected to surface elemental analysis. The instrumentation system employs an electron beam to create X-rays, which are focused on a small portion of the substrate (media) surface. Irradiation of the surface releases a specific energy signature (wavelength) for each element, which is detected using an Energy Dispersive Spectrophotometer (EDS). The Electron Microbeam/EDS system enables semi-quantitative estimation of the mass percentages of elements on the media surface, which can be used to deduce the presence of specific chemical compounds. It should be realized that elemental analysis by EDS is only semi-quantitative in nature, and that the limited project scope did not permit specific methods development for this project. In addition, SEM images represent only a small portion of the overall surface area of even a single media particle.

SEM images of media surfaces are shown in Figures 22 and 23. A comparison of the appearance of the sulfur surface in new condition (Figure 22a) and after 246 days in Column 2A (Figure 22b) shows an increase in roughness. The increase in surface roughness is consistent with the slow dissolution and release of sulfur, which is the operating principal of sulfur-based denitrification filters. A comparison of the appearance of the expanded clay surface in new condition (Figure 23a) and after 246 days in Column 1B (Figure 23b) shows a decrease in

roughness. The decrease in surface roughness is consistent with the accumulation of organic matter in the form of active microbial cells, microbial exudate materials such as polysaccharides, and particulate and colloidal components of wastewater. Accumulation of organic matter and microbial mass on the surfaces of media in unsaturated filters is the operating principal of aerobic filters used in onsite systems for removal of BOD and ammonium.

EDS results for media samples showed several general trends which corroborate with features of the media evaluation experiments. Fresh sulfur and granular rubber media had mass fractions of 84% sulfur and 76% carbon, respectively, corresponding to expected elemental compositions of these media. The calcium content of oyster shell media was 27%, corresponding to the calcium carbonate composition of oyster shell. Clinoptilolite and expanded clay media had aluminum contents of 5 to 10% corresponding to composition of these minerals. Carbon and nitrogen contents increased reflecting the establishment of microbial biofilms and organic matter accumulation on media surfaces and the significant oxygen and nitrogen content in biomass.

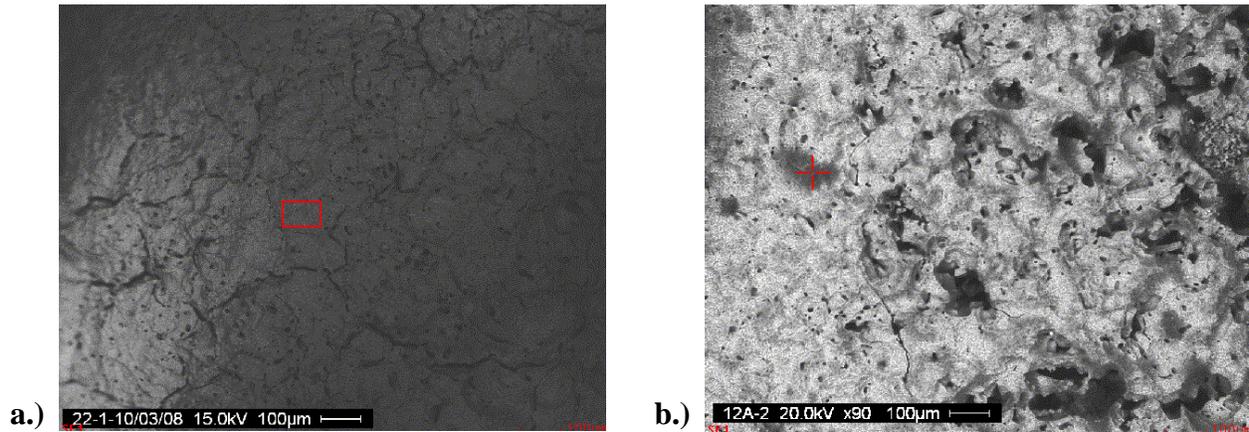


Figure 22 Sulfur particle a.) new media, b. Column 2A, 21 in. from entrance

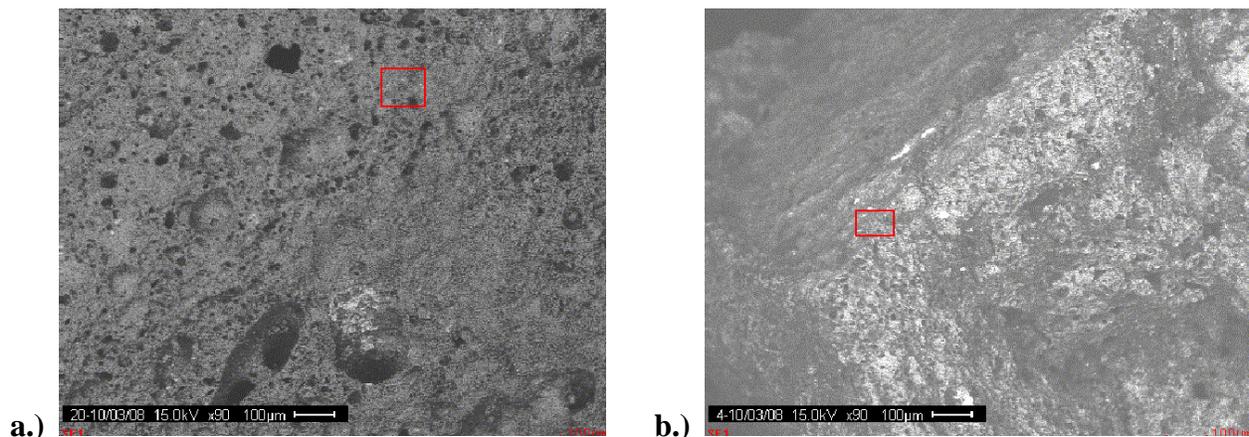


Figure 23 Expanded clay particle a.) new media, b. Column 1B, 1 to 2 in. depth

Conclusions

Three two-stage passive media filters were operated through eight months to treat septic tank effluent. The systems used no aerators, a single wastewater pump, and otherwise operated in passive mode. The following conclusions are based on five monitoring events conducted over 122 days from Day 123 to day 245.

- Average hydraulic loading rates of septic tank effluent applied to Stage 1 filters with clinoptilolite, expanded clay, and tire crumb media were 2.82, 2.96 and 2.83 gallons per square foot per day, respectively.
- Total nitrogen in septic tank effluent averaged 66.9 mg/L with a standard deviation of 6.2 mg/L.
- Total Nitrogen (TN) removal efficiencies for Two-Stage Systems averaged 96.8, 95.1 and 86.6%, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent Total Nitrogen (TN) concentrations for Two-Stage Systems averaged 2.2, 3.2, and 10.4 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Total Inorganic Nitrogen (TIN) removal efficiencies for Two-Stage Systems averaged 99.2, 99.0, and 92.2 %, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent Total Inorganic Nitrogen (TIN) concentrations for Two-Stage Systems averaged 0.53, 1.3 and 6.1 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Effluent ammonium nitrogen ($\text{NH}_4^+\text{-N}$) concentrations for Stage 1 filters averaged 0.028, 0.17 and 4.2 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Average septic tank effluent carbonaceous five day biochemical oxygen demand was 137 mg/L.
- C-BOD₅ removal efficiencies for Stage 1 filters were greater than 94% for clinoptilolite, expanded clay and granular rubber media.
- Effluent C-BOD₅ concentrations in Stage 1 filters were less than 8 mg/L for clinoptilolite, expanded clay and granular rubber media.
- Average dissolved oxygen in unsaturated (Stage 1) effluents were 6.92, 6.65 and 4.86 mg/L, respectively, for clinoptilolite, expanded clay and tire crumb media.
- Average dissolved oxygen in anoxic filter effluents (Stage 2) were 0.06, 0.06 and 0.12 mg/L, respectively, for sulfur media percentages of 75, 60, and 45%.
- For systems 1,2 and 3, the average decline in total alkalinity as CaCO_3 in aerobic filters (Stage 1) was 362 to 471 mg/L, while alkalinity increase in anoxic filters (Stage 2) was 148 to 210 mg/L.
- Media from Stage 1 and 2 columns exhibited a generally similar appearance to new filter media after 246 days of operation.

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APPENDIX A

NELAC CERTIFIED LABORATORY WATER QUALITY DATA

Sample Event 1

Sample Point	Influent	System 1		System 2		System 3	
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent
TKN	79	1.9	3.9	0.05	4.5	9.5	14
NH ₃ -N	66	0.02	0.75	0.10	2.3	5.5	7.1
(NO ₃ +NO ₂)-N	0.04	28	0.044	73.00	0.025	60	0.079
C-BOD ₅	130	<8	-	<8	-	<8	-

Sample Event 2

Sample Point	Influent	System 1		System 2		System 3	
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent
TKN	98	0.046	2.4	0.05	3.4	26.0	20
NH ₃ -N	91	0.020	0.61	0.68	1.1	15.0	14
(NO ₃ +NO ₂)-N	0.025	79	0.025	91	0.025	90	5
C-BOD ₅	160	4	-	3.50	-	8.4	-

Sample Event 3A

Sample Point	Influent	System 1		System 2		System 3	
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent
C-BOD ₅	120	< 2	-	<2	-	<2	-

Sample Event 3B

Sample Point	Influent	System 1		System 2		System 3	
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent
TKN	56	0.120	1.2	0.450	1.8	3.0	4.5
NH ₃ -N	47	0.040	0.33	0.04	0.64	0.07	1.7
(NO ₃ +NO ₂)-N	0.025	54	0.025	56	0.03	52	1.4

Sample Event 4

Sample Point	Influent	System 1		System 2		System 3	
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent
TKN	51	0.87	1.5	1.30	3.1	3.3	3.2
NH ₃ -N	47	0.02	0.15	0.02	1.1	0.075	0.56
(NO ₃ +NO ₂)-N	0.025	55	0.041	52	0.10	53	0.062

Sample Event 5

Sample Point	Influent	System 1		System 2		System 3	
		Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent	Stage 1 Effluent	Stage 2 Effluent
TKN	50	0.82	1.6	0.96	2.8	2.1	3.4
NH ₃ -N	41	0.04	0.67	0.02	1.1	0.04	0.40
(NO ₃ +NO ₂)-N	0.25	40	0.025	41	0.025	40	0.13