THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**BIOLOGICAL WASTEWATER TREATMENT – NITRIFICATION AND DENITRIFICATION FOR NITROGEN REDUCTION**	
APPLICATION:	**REDUCTION OF NITROGEN IN DOMESTIC WASTEWATER FROM INDIVIDUAL RESIDENTIAL HOMES**	
TECHNOLOGY NAME:	**AMPHIDROME™ MODEL SINGLE FAMILY SYSTEM**	
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NSF International (NSF) operates the Water Quality Protection Center (WQPC) under the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program. The WQPC evaluated the performance of a submerged growth biological filter treatment system for nitrogen removal for residential applications. The Barnstable County (Massachusetts) Department of Health and the Environment (BCDHE) performed the verification testing. This verification statement provides a summary of the test results for the F.R. Mahony & Associates, Inc. (FRMA), Amphidrome™ Model Single Family System.

The ETV program was created to facilitate deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups consisting of buyers, vendor organizations, and permitters, and the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and verifiable quality are generated and that the results are defensible.

ABSTRACT

Verification testing of the Amphidrome™ Model Single Family System was conducted over a thirteen-month period at the Massachusetts Alternative Septic System Test Center (MASSTC) located at Otis Air National Guard Base in Bourne, Massachusetts. Sanitary sewerage from the base residential housing was used for the testing. An eight-week startup period preceded the verification test to provide time for the development of an acclimated biological growth in the Amphidrome™ System. The verification test included monthly sampling of the influent and effluent wastewater, and five test sequences designed to test the unit response to differing load conditions and power failure. The Amphidrome™ System proved capable of removing nitrogen from the wastewater. The influent total nitrogen (TN), as measured by TKN, averaged 37 mg/L with a median of 37 mg/L. The effluent TN (TKN plus nitrite/nitrate) concentration averaged 15 mg/L over the verification period, with a median concentration of 14 mg/L, with an average TKN concentration of 8.5 mg/L and a median concentration of 8.3 mg/L. The system operating conditions (pump and float settings, aeration cycles), are controlled by a programmable logic controller (PLC) and were adjusted four times during the first two months of the verification test, and after six months of test operation. In general, the mechanical equipment, pumps, level switches and alarms operated properly during the test, except for a discharge pump failure after nine months of operation, and the return pump slipping off its pedestal in June 2001. The Amphidrome™ System is sophisticated and requires a trained operator to monitor the system and ensure the pump cycle times, aeration periods, and backwash settings are set to the site specific conditions.

TECHNOLOGY DESCRIPTION

The following description of the F.R. Mahoney Amphidrome System was provided by the vendor and does not represent verified information.

The Amphidrome™ System consists of a submerged growth sequencing batch reactor used in conjunction with an anoxic/equalization tank (standard 2,000 gallon tank, but a 1,500 gallon two compartment septic tank for this test), and a clear well tank for wastewater treatment. The anoxic tank provides solid-liquid separation, and anoxic conditions for denitrification. The bioreactor consists of a deep bed sand filter, which alternates between aerobic and anoxic treatment. The reactor operates similar to a biological aerated filter, except that the reactor changes from aerobic to anoxic conditions during sequential cycling of the unit. Air, supplied by a blower, is introduced at the bottom of the filter by a distribution system that produces fine bubbles to enhance oxygen transfer. According to the vendor, the unique system design allows soluble organic removal, nitrification, and denitrification to occur in one reactor.

The cyclical action of the system is created by allowing a batch of wastewater to pass by gravity flow from the anoxic/equalization tank through the submerged sand filter (down flow mode) and into the clear well. The flow is then reversed using a pump to move water from the clear well up through the filter and into a return pipe, which carries the wastewater back to the anoxic tank. These cycles are repeated multiple times during a 24-hour period. The conditions in the filter change from aerobic to anoxic based on the timing of the aeration cycles, with a typical cycle being 3 to 5 minutes of aeration, followed by 15 minutes without aeration. The filter is backwashed using a combination of aeration and pumped water from the clear well. Treated wastewater is discharged once per day from the clear well by pumping to the receiving location. The Amphidrome™ System is supplied with a programmable logic controller (PLC), which controls the frequency and duration of pump operation, aeration cycles, backwash, and discharge, as well as all alarm functions and data collection.

VERIFICATION TESTING DESCRIPTION

Test Site

The MASSTC site is located at the Otis Air National Guard Base in Bourne, Massachusetts. The site uses domestic wastewater from the base residential housing, and sanitary wastewater from other military buildings in testing. A chamber located in the main interceptor sewer to the base wastewater treatment facility provides a location to obtain untreated wastewater that is pumped to the site dosing channel after passing through a one-inch bar screen. The channel is equipped with four recirculation pumps that are spaced along the channel length to ensure mixing and wastewater of similar quality in the channel. Wastewater is dosed to the test unit using a pump submerged in the dosing channel. A programmable logic controller (PLC) is used to control the pumps and the dosing sequence or cycle.

Methods and Procedures

The Amphidrome™ System was installed by a contractor in December 1999 as part of an earlier test program. The unit was installed in accordance with the installation instructions supplied by FRMA. In order to prepare for ETV testing, the entire system was emptied of wastewater and cleaned. Solids were removed from the septic tank and the clear well, all pumps, lines, and associated equipment were cleaned, and the sand filter was flushed repeatedly by recirculating clean water through the system. The entire system was then drained and remained off until the startup period. On January 15, 2001, the septic tank was filled with wastewater and the standard dosing sequence began. An eight-week startup period allowed the biological community to become established and the operating conditions to be monitored.

System monitoring during the startup period included visual observations, routine calibration of the dosing system, and collection of influent and effluent samples. Six sets of samples were collected for analysis over the startup period. Influent samples were analyzed for pH, alkalinity, temperature, BOD_5, TKN, NH_3, and TSS analyses. Effluent samples were analyzed for pH, alkalinity, temperature, $CBOD_5$, TKN, NH_3, TSS, dissolved oxygen, NO_2^- and NO_3^-.

Verification testing consisted of a thirteen-month period, with five stress test sequences simulating household conditions. The five stress sequences were performed at two-month intervals, and included washday, working parent, low load, power/equipment failure, and vacation conditions. Monitoring for nitrogen reduction was accomplished by measuring the nitrogen species (TKN, NH_3, NO_2, NO_3), while biochemical and carbonaceous oxygen demand (BOD_5/$CBOD_5$) and other basic parameters (pH, alkalinity, TSS, temperature) were monitored to provide information on overall system performance. Operational characteristics, such as electric use, residuals generation, maintenance tasks and labor, hardware durability, noise and odor production were also monitored.

The Amphidrome™ System was tested at the design capacity of 400 gallons per day (± 10 percent) for the entire thirteen-month test, except during the low load and vacation stress tests. The Amphidrome™ System was dosed 15 times per day with approximately 26.7 gallons of wastewater per dose. The unit received five morning doses, four mid-day doses, and six evening doses. Dosing volume was controlled by adjusting pump run time for each cycle, based on twice-weekly calibration of the dosing pump.

The sampling schedule included collection of twenty-four hour flow weighted composite samples of the influent and effluent wastewater once per month under normal operating conditions. Stress test periods were sampled on a more intense basis with six to eight composite samples collected during and following each stress test period. Five consecutive days of sampling occurred in the twelfth month of the verification test. All composite samples were collected using automatic samplers located at the dosing channel (influent sample) and at the discharge of the unit. Grab samples were collected on each sampling day to monitor the system pH, dissolved oxygen, and temperature.

Samples were collected and preserved as appropriate, and transported to the laboratory. All analyses were performed according to "*Standard Methods for the Examination of Water And Wastewater*", 19th Edition, 1998. Washington, D.C. or other EPA approved methods. An established quality assurance/ quality control (QA/QC) program was used to monitor field sampling and laboratory analytical procedures. QA/QC requirements included field duplicates, laboratory duplicates and spiked samples, and appropriate equipment/instrumentation calibration procedures. Details on the analytical methods and QA/QC procedures are provided in the full Verification Report.

PERFORMANCE VERIFICATION

Overview

Evaluation of the Amphidrome System at MASSTC began on March 13, 2001, when the system pumps were activated and the wastewater dosing started. Verification testing continued for thirteen months until April 17, 2002. During the verification test, 53 sets of samples of the influent and effluent were collected to determine the system performance.

Startup

The unit started up with no difficulty. The installation instructions were easy to follow and installation proceeded without difficulty. FRMA representatives setup the PLC, which controlled all recirculation, aeration, backwash, and discharge times. No changes were made to the unit during the startup period and no special maintenance was required.

The Amphidrome™ System showed a reduction in $CBOD_5$ and TSS after the first week of operation, and continued to improve over the next seven weeks. At the end of the eight-week startup, effluent $CBOD_5$ was 5.0 mg/L and TSS was 4 mg/L. There was some TN reduction occurring, with effluent concentrations varying between 21 and 28 mg/L, compared to influent concentrations of 34 to 46 mg/L. However, it did not appear that the nitrifying organisms were firmly established in the system. Low wastewater temperature was considered the primary reason for the slow trend toward improved reduction in TN as the wastewater temperature was no higher than about 8 ^{o}C through March 13.

Verification Test Results

The verification protocol requires sampling during and following the major stress periods. This results in a large number of samples being clustered during five periods, with the remaining samples spread over the remaining months (monthly sampling). Both average (mean) and median results are presented, as the median values compared to average values can help in analyzing the impacts of the stress periods.

The TSS and BOD_5/$CBOD_5$ results for the verification test, including all stress test periods, are shown in Table 1. The influent wastewater had an average BOD_5 of 210 mg/L (median of 200 mg/L) and average TSS of 150 mg/L (median of 130 mg/L). The Amphidrome™ effluent had an average $CBOD_5$ of 4.9 mg/L, with a median $CBOD_5$ of 4.4 mg/L. The average effluent TSS was 5 mg/L and the median was 3 mg/L. During the thirteen-month test, effluent $CBOD_5$ concentrations typically ranged from 1 to 10 mg/L, except for two samples, and TSS ranged from 1 to 11 mg/L, except for 3 samples.

Table 1. BOD_5/$CBOD_5$ and TSS Data Summary

	BOD_5 Influent (mg/L)	$CBOD_5$ Effluent (mg/L)	Percent Removal	TSS Influent (mg/L)	TSS Effluent (mg/L)	TSS Percent Removal
Average	210	4.9	97	150	5	96
Median	200	4.4	98	130	3	98
Maximum	370	20	>99	340	40	>99
Minimum	67	<2.0	90	61	1	64
Std. Dev.	73	3.5	1.5	67	7	6.0

Note: The data in Table 1 are based on 53 samples.

The nitrogen results for the verification test, including all stress test periods, are shown in Table 2. The influent wastewater had an average TKN concentration of 37 mg/L (median of 37 mg/L) and an average ammonia nitrogen concentration of 23 mg/L (median of 23 mg/L). The average TN concentration in the influent was 37 mg/L (median of 37 mg/L), based on the assumption that the nitrite and nitrate concentrations in the influent were negligible. The Amphidrome™ System effluent had an average TKN concentration of 8.5 mg/L (median of 8.3 mg/L) and an average NH_3-N concentration of 7.0 mg/L (median of 6.1 mg/L). The nitrite concentration in the effluent averaged 0.27 mg/L, while effluent nitrate concentrations averaged 6.4 mg/L (median of 5.5 mg/L). Total nitrogen was determined by adding the daily concentrations of the TKN (organic plus ammonia nitrogen), nitrite, and nitrate. Average TN in the Amphidrome™ System effluent was 15 mg/L (median 14 mg/L) for the thirteen-month verification period. The System averaged a 59 percent reduction of TN for the entire test, with a median removal of 62 percent.

Table 2. Nitrogen Data Summary

	TKN (mg/L)		Ammonia (mg/L)		Total Nitrogen (mg/L)		Nitrate (mg/L)	Nitrite (mg/L)	Temperature (°C)
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent	Influent
Average	37	8.5	23	7.0	37	15	6.4	0.27	15
Median	37	8.3	23	6.1	37	14	5.5	0.25	14
Maximum	45	31	29	25	45	31	19	1.3	22
Minimum	24	1.0	18	0.4	24	10	<0.1	0.08	8.4
Std. Dev.	4.1	6.4	2.4	4.7	4.1	3.6	4.5	0.20	4.3

Note: The data in Table 2 are based on 53 samples, except for temperature, which is based on 42 samples.

Verification Test Discussion

Beginning in late March and early April, temperatures began to increase and the nitrifying population clearly became more firmly established, as indicated by the decrease in the effluent TKN and ammonia concentrations to 10 mg/L or less. Nitrate concentrations increased somewhat in this same period, but the data show that denitrification was also occurring. Organic concentration in the effluent was low, as measured by $CBOD_5$ concentrations of 4.0-5.0 mg/L. During May and June, the TN concentration in the effluent was in the range of 13 to 16 mg/L. The washday stress test in May 2001 showed no negative impact on nitrogen reduction.

In early July 2001, the data show that there was loss of the nitrifying population in the unit, with TKN and ammonia nitrogen levels in the effluent increasing to 31 and 25 mg/L, respectively. The nitrate levels dropped to less than 0.1 mg/L, which would be more typical of influent wastewater. On June 21, it was discovered that the return pump had slipped off its pedestal, disconnecting the return line and stopping the return flow through the sand filter to the anoxic tank. It is estimated that the wastewater was treated by only a single pass through the sand filter for about two weeks before the return pump problem was corrected and proper operation was restored. The lack of recycle flow apparently caused the loss of nitrification in the system.

The working parent stress test started on July 9 and continued until July 13, 2001. The Amphidrome System began to recover from the June upset with improved $CBOD_5$ and TSS performance, but the nitrification process was much slower in its recovery. Some removal of TKN, ammonia and TN occurred during the working parent stress test monitoring in mid-July, but at a lower performance level than during the previous two months. During the stress test, there was no sign that the stress test itself was having any additional impact on the system.

The monthly samples on August 1 and September 5 showed an improvement in the removal of TKN and ammonia, indicating that the nitrifying population was re-established. Nitrate levels in the effluent increased somewhat (from 3.3 to 7.9 mg/L) and TN in the effluent was in the 14 to 15 mg/L range.

The low load stress test began on September 17 and continued until October 8, 2002. During this stress period, the nitrification process became very efficient, dropping the TKN and ammonia levels in the effluent to less than 1 mg/L. Nitrate concentrations increased to 14 to 19 mg/L and TN was 14 to 20 mg/L. As the low load stress test ended, virtually all of the TN in the effluent was in the form of nitrate. Once the system returned to normal full flow conditions, the TKN and ammonia concentrations in the effluent rose slightly (from 1.2 to 4.8 mg/L), and nitrate concentrations decreased to 10 to 14 mg/L. Overall, the TN removal performance was steady at the end of the monitoring period with effluent concentrations of 10 to 14 mg/L, similar to the results obtained in May prior to the upset, except that the primary component of the TN concentration was nitrate. The vendor decreased the aeration time by ten percent to try to improve denitrification performance.

During the November 2001 to January 2002 period, including the power/equipment failure stress test in December, the Amphidrome System produced steady results, with TN in the effluent of 10 to 16 mg/L, a removal efficiency of 57 to 77 percent. TN in the effluent was composed of TKN and nitrate, similar to the two month period prior to the June upset condition. The power/equipment failure stress test, performed on December 3 did not have a major impact on the system.

The vacation stress test (no influent flow for eight days) was performed in February 2002. The effluent TKN and ammonia concentrations decreased in the samples taken immediately after flow was resumed to the system. The nitrate levels increased in a manner similar to the findings following the low load stress test. TN concentrations remained steady in the effluent ranging from 12 to 17 mg/L. By the end of the post stress test monitoring period, effluent concentrations consisted of TKN at 5.5 mg/L and nitrate at 6.8 mg/L. These data, supported by the results from the low load stress test, suggest that the Amphidrome™ System responded to decreases in flow by exhibiting improved nitrification and less denitrification. The TN performance, however, did not change much, with effluent concentrations remaining near the long-term average and median of 15 mg/L and 14 mg/L, respectively.

The Amphidrome System performance remained consistent for the duration of the verification test, with TKN and ammonia nitrogen effluent concentration consistently in the 7.6 to 9.5 mg/L range. The nitrate levels remained in the 3.0 to 4.8 mg/L range. The TN concentration in the effluent ranged from 11 to 15 mg/L.

The verification test provided a sufficiently long test period to collect data that included both a long run of steady performance by the Amphidrome™ System and a period of reduced nitrification and denitrification efficiencies. During the months of April through June, following startup, the TN removal was in the 45 to 71 percent range, with effluent concentrations typically in the 13 to 16 mg/L range. The June upset condition, caused by the problem with the return pump, dramatically impacted the nitrification process in early July. The system recovered from the upset by the end of July and continued to remove TN. During the last eight months of the verification test, the TN removal was in the 52 to 77 percent range. Effluent TN concentration ranged from 10 to 20 mg/L, with most concentrations in the 13 to 15 mg/L range. Data collected from the two low or no flow stress tests indicated that overall system performance for TN was not significantly impacted, but the effluent concentrations of TKN, ammonia and nitrate changed significantly during these lower flow periods.

Operation and Maintenance Results

Noise levels associated with mechanical equipment were measured once during the verification period using a calibrated decibel meter. Measurements were made one meter from the unit, and one and a half meters above the ground, at 90° intervals in four (4) directions. The average decibel level was 56.7, with a minimum of 54.3 and maximum of 60.0. The background level was 37.7 decibels.

Odor observations were made monthly for the last eight months of the verification test. The observation was qualitative based on odor strength (intensity) and type (attribute). Observations were made during periods of low wind velocity (<10 knots), at a distance of three feet from the treatment unit, and recorded at 90° intervals in four directions. There were no discernible odors during any of the observation periods.

Electric power use was monitored by a dedicated electric meter serving the Amphidrome™ System. The average electrical use was 4.1 kW/day. However, there was one two-week period of high electrical use in June 2001, when the return pump slipped off its pedestal, disconnecting the return line and pumping continuously for about two weeks.

During the verification test, one other mechanical problem occurred when the discharge pump failed. The high water alarm sounded and a service call was placed to FRMA. They responded within twenty-four hours and replaced the pump. Overall, the treatment unit appeared to be a durable design. The piping is PVC, which is appropriate for the applications. Pump and level switch life is always difficult to estimate, but the components used were made for wastewater applications. The PLC, which is critical to the operation of the system, functioned properly throughout the test. The system does not require or use any chemicals as part of normal operating conditions.

The Amphidrome™ System is a somewhat complex, PLC controlled wastewater treatment system, using a sophisticated operating cycle that must be setup and optimized to site specific and changing conditions. During the first two months of verification testing (April and May), the vendor adjusted the PLC on four occasions. The airflow was adjusted in early April and the backwash cycle was adjusted in mid-May. On May 24, the cycle times were adjusted to try to improve the performance, but were returned to the initial conditions on June 1. The anoxic cycle was adjusted on October 21, and the fixed airflow time was reduced by 10 percent on October 25, 2001 to try to improve denitrification. These adjustments were made to try to match the aerobic/anoxic cycles to the wastewater and system conditions. Based on these observations, it will be necessary for homeowners to have a qualified maintenance organization operate and maintain the system.

Quality Assurance/Quality Control

NSF International completed QA audits of the MASSTC and BCDHE laboratory during testing. NSF personnel completed a technical systems audit to assure the testing was in compliance with the test plan, a performance evaluation audit to assure that the measurement systems employed by MASSTC and the

BCDHE laboratory were adequate to produce reliable data, and a data quality audit of at least 10 percent of the test data to assure that the reported data represented the data generated during the testing. In addition to quality assurance audits performed by NSF International, EPA QA personnel conducted a quality systems audit of NSF International's QA Management Program, and accompanied NSF during audits of the MASSTC and BCDHE facilities.

Original signed by *Hugh W. McKinnon* *7/23/03*	*Original signed by* *Gordon E. Bellen* *7/23/03*
Hugh W. McKinnon Date Director National Risk Management Research Laboratory Office of Research and Development United States Environmental Protection Agency	Gordon E. Bellen Date Vice President Research NSF International

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Availability of Supporting Documents

Copies of the *ETV Protocol for Verification of Residential Wastewater Treatment Technologies for Nutrient Reduction*, dated November 2000, the Verification Statement, and the Verification Report are available from the following sources:

ETV Water Quality Protection Center Manager (order hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140
NSF web site: http://www.nsf.org/etv (electronic copy)
EPA web site: http://www.epa.gov/etv (electronic copy)

(NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.)

EPA's Office of Wastewater Management has published a number of documents to assist purchasers, community planners and regulators in the proper selection, operation and management of onsite wastewater treatment systems. Two relevant documents and their sources are:

1. *Handbook for Management of Onsite and Clustered Decentralized Wastewater Treatment Systems* http://www.epa.gov/owm/onsite

2. *Onsite Wastewater Treatment Systems Manual* http://www.epa/gov/owm/mtb/decent/toolbox.htm