Enhanced Nutrient Removal by Extended Aeration

Christina M. Edvardsson
MicroSepTec, Inc., 23112 Alcalde Drive, Suite C, Laguna Hills, CA 92653

Presented at
11th Northwest On-Site Wastewater Treatment Short Course and Equipment Exhibition,
April 3-4, 2002, University of Washington, Seattle, Washington

INTRODUCTION

Approximately 25% of U.S. households are using an on-site wastewater treatment system (U.S. EPA, 1980). These systems include a variety of components and configurations, the most common being the septic tank/soil absorption system. The number of onsite systems is increasing each year. More than 35% of new homes constructed are built with septic tanks, cesspools, or chemical toilets.

The limitation of the septic tank is that it does not remove many of the nutrients in wastewater. It relies on the soil and microbes in the soil for completing the treatment. This is a very ineffective treatment, which may result in contamination of the groundwater. It used to be that as long as the water disappeared in the ground, the system was working fine. This is obviously not true, if the water is not adequately treated before it “disappears in the ground”, it may cause groundwater contamination, resulting in high nitrate concentrations in the drinking water. Depending on the soil conditions, there is also a risk for the high nutrient loading to contaminate the receiving waters. The effect of high nutrient concentrations in streams, lakes, or bays is depletion of dissolved oxygen, which may cause the water to become murky and odorous with increased aquatic plants and algae growth and decreased fish population.

A high efficiency onsite residential treatment unit, wherein the entire treatment of the wastewater takes place inside the unit and not in the soil, takes care of this problem. Such a unit can also be used in areas with shallow ground water tables, in nitrogen sensitive areas or areas with poor soil conditions.

This paper will describe such a unit, called the EnviroServer, which was developed by MicroSepTec to provide a complete treatment system for the customer including nutrient removal, disinfection, and on-site destruction of sludge with clean water as the only residual. The only work left for the soil and the plants are to absorb the clean water. The system has been evaluated and certified by various third-party organizations such as the University of California Riverside (UCR), the Ventura Regional Sanitation District (VRSD), and NSF International. Currently, it is also part of the National Decentralized Community Wastewater Demonstration Project in Deschutes County, Oregon.

DESIGN OF TREATMENT UNIT

The EnviroServer system consists of one fiberglass tank installed below ground and two enclosures installed above ground, typically on the outside wall of the house, which hold the air compressors and on-site controller. It comes in three different sizes based on the hydraulic load of the application; 600 GPD, 1200 GPD, and 1500 GPD. Figure 1 shows a schematic of the unit. The tank contains five compartments, which can be accessed through four different man-ways that extends up to ground level. All the equipment inside the tank is made so it can easily be replaced or serviced through the four man-ways. The Enviroserver unit itself operates continuously and on demand. The influent feed from the residence is by gravity flow similar to an activated sludge plant. Residential wastewater enters the first compartment where primary clarification takes place. The primary clarified wastewater along with the floatables including grease then overflows to the first aerated compartment where it undergoes aerobic digestion. Biological $CBOD_5$ (Carbonaceous Biochemical Oxygen Demand) removal and nitrification takes place in this and the subsequent aerated compartment. To promote $CBOD_5$ removal and nitrification both compartments contain moving media for attached biofilm growth. Biologically treated wastewater underflows into the fourth compartment where final clarification takes place.

A small submersible pump returns settled biomass and nitrified effluent from the secondary clarifier to the primary clarifier. Settled biomass from the primary clarifier is periodically pumped from the bottom of the compartment to the thermal processor where the solids are retained by a stainless steel sieve and the water is drained back to the primary clarifier. After a set number of pump cycles the control system initiates the thermal decomposition of the retained solids, which includes drying, gasification, and oxidation at controlled temperatures. The exhaust gas is forced back into the water in the first compartment, which further scrubs the gases to remove any remaining particulates, gas products, and potential odor before it is vented together with the air in the tank through the normal vent at the roof of the house. The controlled temperatures in combination with forced air results in minimum emissions. The end product is an inert residual of carbon and ash that is flushed back into the tank the next time the primary clarifier sludge pump is turned on. Recirculation of settled biomass from the secondary clarifier to the primary clarifier in combination with periodic thermal processing also helps maintain low effluent TSS (Total Suspended Solids) concentrations.

Enhanced nitrogen removal also becomes possible when the aerobically treated and nitrified wastewater from compartment two and three is recycled from compartment four to compartment one. The NO_3-N in the aerobically treated wastewater serves as the terminal electron acceptor and the raw wastewater influent entering the first compartment serves as the necessary carbon source for the denitrification reactions. Anoxic conditions are normally maintained throughout the day because compartment one is not aerated and because incoming raw wastewater quickly depletes any available oxygen despite the periodic influx of dissolved oxygen that is introduced into the first compartment during recycle pumping, assuming the recycle ratio is in balance with the incoming wastewater.

The clarified and treated wastewater next flows from the fourth compartment through a chlorination unit into the chlorination contact and effluent storage tank. The chlorination contact tank is designed for a hydraulic residence time of 90 minutes for complete coliform destruction.

The EnviroServer System is controlled and monitored by a custom computer control system. The computer is capable of detecting failures of electrical and mechanical components critical to the treatment processes and delivering signals both remotely via a telephone connection and locally with a visible and audible alarm. The most important alarms are high tank level, pump failures, air compressor failure, incomplete thermal decomposition cycle, and disinfection failure.

All on-site control systems are connected to MicroSepTec’s service database computer. If one of the EnviroServers goes into alarm, the onboard computer will call up the service computer and report the alarm. The service computer will then email and call the assigned Service Technician for this unit. The Service Technician can then access the service computer via the Internet and check the status, current and historical alarms, and service reports for that unit. This will tell the technician what is wrong before going out and servicing the unit. It will also indicate the urgency, which may allow time to schedule the service visit instead of responding to an emergency.

The service computer can also be accessed by Regulators via Internet, which allows them to check the status of the systems in their area without leaving the office. Each county is assigned its own password. If effluent water samples have been taken, the lab result is reported in the service database.

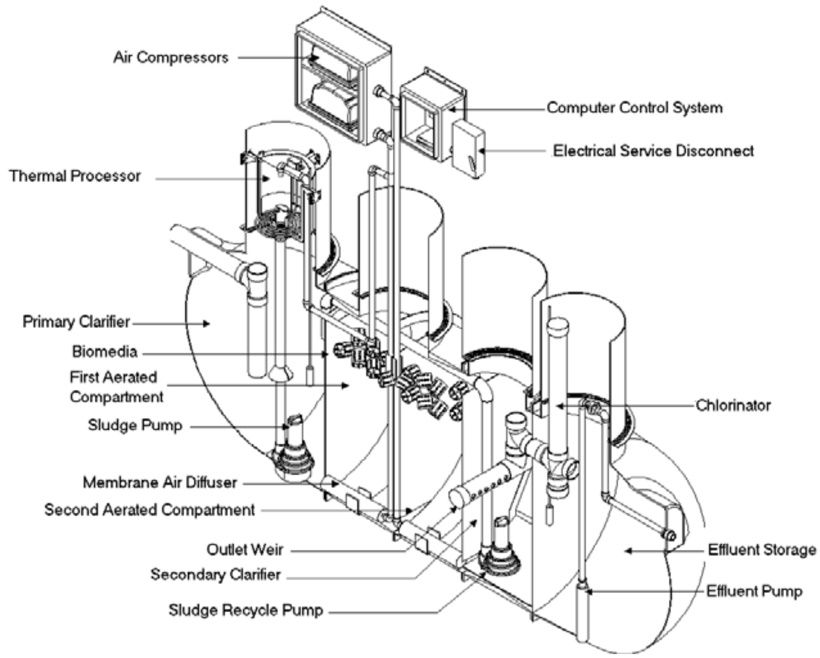

Figure 1. Schematic rendering of an Enviroserver residential treatment system.

THIRD-PARTY EVALUATIONS METHODOLOGIES

There are currently 64 EnviroServer Units installed throughout the US, Canada and Mexico. The first one was put into operation close to four years ago. The systems are NSF[1] certified and passed the Standard 40 testing in December of 1999. Concurrently with the NSF Standard 40 testing, MicroSepTec contracted with the University of California Riverside (UCR) to perform a third-party evaluation under real-life conditions (Wistrom et. al., 1999). Even though the NSF testing is very well recognized in most states, it only tests for $CBOD_5$, TSS, pH, color, odor, oily film, and foam, and the entire testing is performed using well-mixed municipal sewage as the feed. Since flow rates and mass loading rates to a residential wastewater treatment unit are highly variable, it was felt that the EnviroServer should be tested under these conditions.

The purpose of the UCR study was to assess influent and effluent characteristics during treatment of wastewater from a single-family owned residence to provide additional insight regarding the mechanisms for enhanced nutrient removal. Special provisions were made to characterize the influent. A sample well equipped with a mixer to homogenize incoming raw wastewater was installed on the influent line and equipped with an automatic sampler. The influent and effluent were characterized as 24-hour average concentrations over a two-month period and as hourly concentrations for four 24-hour periods. The influent and effluent quality were measured in terms of TDS, TSS, TOC, $CBOD_5$, TKN, Ammonia-N, Nitrate-N, Total Phosphorous, Reactive Phosphorous, Total and Fecal Coliform. A flow meter complete with data logger was installed on the residential water line to measure the potable water consumption on a continuous basis. Because all water consumed by the residents was discharged to the test facility a representative estimate of wastewater flow rates were obtained assuming that the time delay between usage and discharge did not adversely affect the analysis. Figure 2 shows the average and standard deviation of hourly flow rates. In this study the average daily flow per capita was 39 gpcd, which is similar to what have been reported for households residing in apartments and mobile home parks that include little or no water for irrigation (Metcalf and Eddy, 1991).

[1] National Sanitation Foundation

In the summer of 2000, MicroSepTec was invited by the Ventura Regional Sanitation District to participate in a "Septic Tank Nutrient Removal Demonstration" project (Ventura Regional Sanitation District, 2001). The demonstration was partially funded by the US EPA. The purpose was to evaluate several advanced wastewater treatment units and to gauge the degree of nutrient removal from typical household wastewater achieved by these units. The project was carried out using municipal sewage as the feed, which was automatically dosed in to each unit simulating the typical diurnal wastewater flow characteristics of a single-family residence as can be seen in Figure 2 from the UCR study. Influent samples were collected biweekly. A refrigerated composite sampler accumulated the sample. Effluent grab samples were taken approximately twice a week. The project also included simulation of vacation stress and high flow weeks.

The next section will discuss the results from these third-party tests and from grab samples taken from actual units in operation.

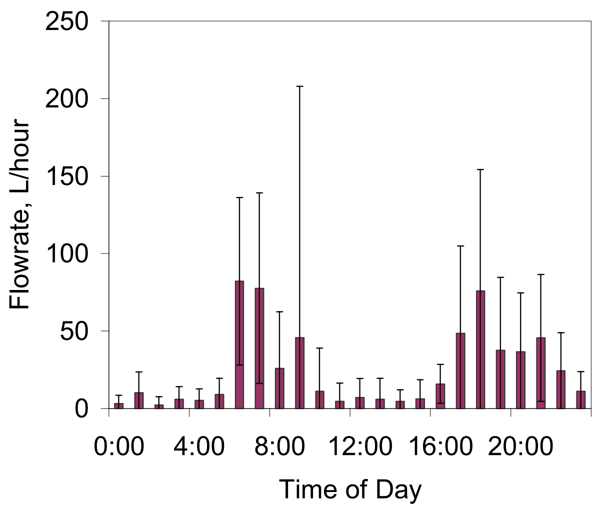

Figure 2. Average hourly flow rates with error bars showing one standard deviation from the UCR study.

TEST RESULTS AND DISCUSSION

Table 1 shows the average results and standard deviations for the three third-party testing of the EnviroServer compared to the performance of a typical septic tank (Metcalf & Eddy, 1991). As can be seen from the numbers, the EnviroServer completes the treatment inside the single tank, whereas the septic tank requires substantial treatment to be done by the soil.

As expected, the removal and final effluent concentration of $CBOD_5$ (organics) and TSS are fairly constant for all studies, but total nitrogen and phosphorous vary. Both these nutrients are very sensitive for the characteristics of the wastewater as it goes through the treatment unit. Nitrification and denitrification are affected by factors like dissolved oxygen (DO), carbon concentration ($CBOD_5$), pH, and temperature. Phosphorus is removed by assimilation into new cell mass, i.e. uptake of the microorganisms. Unfortunately, some of the phosphorus will be released again unless the sludge is wasted as is the case in the EnviroServer's thermal decomposition cycle. This uptake and release are affected by the nitrate and sulfide concentrations, and the DO.

Table 1. Measured concentrations of influent and effluent wastewater constituents.

	$CBOD_5$ mg/l	TSS mg/l	TKN mg/l	Nitrate-N mg/l	Total N mg/l	Total P mg/l
Septic Tank						
Typical Influent:	210-530[2]	237-600	35-80	<1	35-80	10-27
Typical Effluent:	140-200[2]	50-90	25-60	<1	25-60	10-30
EnviroServer, NFS						
Average Influent:	156	229	42.2	0.4	42.6	N/A
Average Effluent:						
Mean	**6**	**8**	2.0	8.8	**10.8**	N/A
Std. Dev.	9	7	0.3	0.3	0.6	
No. of Samples	107	104	5	5	5	
% Removal	96%	96%			75%	
EnviroServer, UCR						
Average Influent:	212	267	43.0	1.1	44.1	19.0
Average Effluent:						
Mean	**6**	**6**	7.0	2.1	**9.1**	**2.0**
Std. Dev.	3	4	4.6	1.5	6.1	0.7
No. of Samples	31	31	24	31	24	31
% Removal	97%	98%			79%	89%
EnviroServer, Ventura						
Average Influent:	178[2]	225	29.8	0.2	30.0	3.2
Average Effluent:						
Mean	**5**[2]	**10**	5.4	10.3	**15.7**	**3.1**
Std. Dev.	2	6	9.7	11.6	11.9	1.5
No. of Samples	19	20	20	21	20	20
% Removal	97%	96%			48%	N/A

The UCR study showed surprisingly high phosphorous removal while the Ventura study showed basically no removal. One possible explanation to this is the higher nitrate concentration for the Ventura study. In the EnviroServer, the denitrification rate is controlled by the recirculation of water from the forth to the first compartment and available carbon in the raw sewage entering the first compartment. The purpose of the carbon in the raw sewage is to deplete any DO coming from the recirculated water, such that the first compartment stays anaerobic. Furthermore, the carbon will work as the required energy source for the denitrification process.

Favorable conditions for the phosphorous uptake is anaerobic atmosphere and fairly high nitrate concentration. As can be seen in Figure 3, both nitrate and phosphorous concentrations stayed low during the start-up and normal phase of the Ventura study, but increased after the vacation stress period. During the vacation stress period, there was no influent for seven days to the treatment unit and without changing the operating parameters of the EnviroServer. Normally during a vacation period, the EnviroServer can automatically (on-line) be put in to a vacation mode, which means that the recirculation rate is decreased and the thermal processor is turned off. If the unit is not put into vacation mode, the first compartment will become aerobic and the denitrification and phosphorous removal will be effected as is shown in Figure 3. This will go back to normal after some period of usage.

[2] BOD_5 – Nitrogenous and Carbonaceous

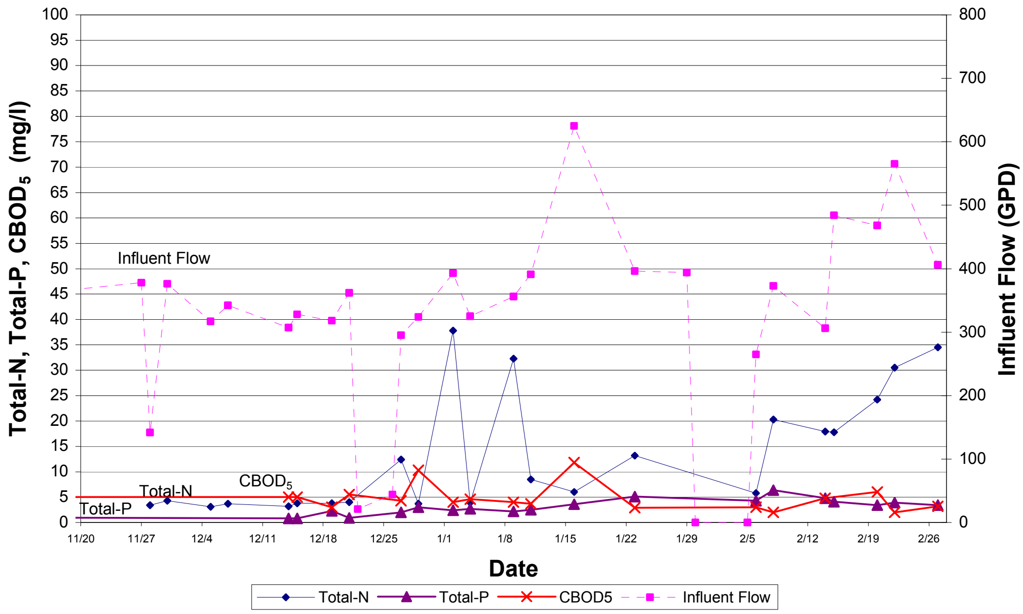

Figure 3. Daily results as a function of sampling date during the Ventura testing.

Part of the objective during the UCR study was to gain a better understanding of the effect of the inherent variability of influent flow rates and wastewater composition on removal efficiency over the short-term. 24-hour track studies were performed on four weekdays during the study period. A track study typically included influent and effluent samples automatically collected every hour. Figure 4 shows the variability in TKN. Despite large variations in the TKN influent concentration, the concentration of TKN in the effluent stays low and fairly constant. Other constituents, like $CBOD_5$ and TSS, followed the same pattern.

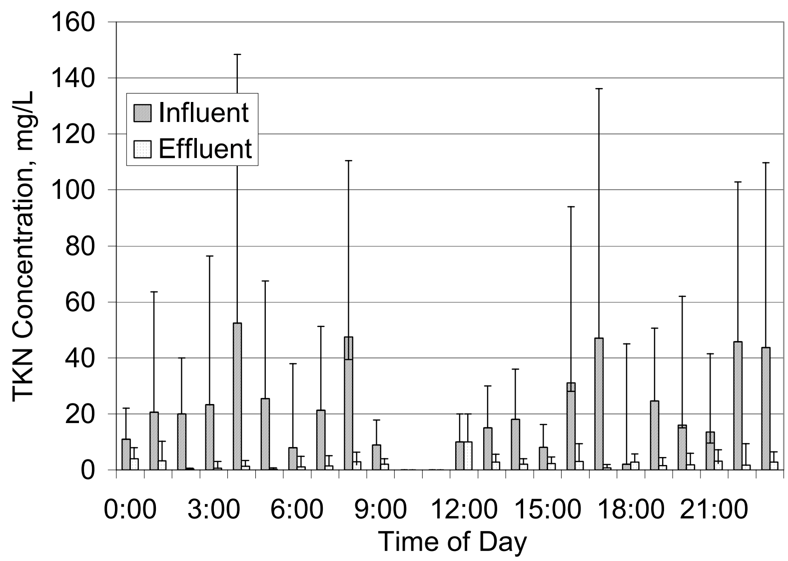

Figure 4. Hourly influent and effluent TKN concentrations for the UCR weekday track study. Error bars show maximum and minimum values. (N=4)

Table 2 shows results from grab sampling of some EnviroServers that have been in operation from one to two years. Some adjustments of the recirculation rate have been done on these units to optimize the denitrification based on site-specific conditions.

Table 2. Test Results from Grab Sampling of EnviroServers currently in operation.

Customer	Application	No. of People	Sampling Date	BOD_5 mg/l	TSS mg/l	TKN mg/l	Nitrate-N mg/l	Total-N mg/l
Vance	4 bedroom residence	4	9/27/00	8	8	3.2	3.6	6.8
Fishburne	4 bedroom residence	2	2/28/01	<2	3	1.1	3.9	5.0
Ziegler	4 bedroom residence	4	2/28/01	3	10	1.9	7.5	9.4
Cooper	6 bedroom residence	4	4/5/01	14	<1	0.2	9.4	9.6
Navarra	Industrial Park	74	8/1/01	3	<10	6.1	9.0	15.1
Colison	4 bedroom residence	N/A	1/12/01	8	14	2.8	4.9	7.7

CONCLUSIONS

Nutrient removal can be done economically and very efficiently in small-scale on-site wastewater treatment units. To consistently achieve below 10 mg/l for all nutrients some adjustments may have to be done initially and during periods of non-usage.

The principal conclusions resulting from the evaluations of the Enviroserver residential wastewater treatment unit are as follows:

- Advanced treatment units do not rely on the soil and its microorganism to complete the treatment as is the case for a regular septic tank.
- Small on-site wastewater units can efficiently remove nutrients like $CBOD_5$ and Total Nitrogen to below 10 mg/l and Total Phosphorous to below 2 mg/l during normal operation. Some adjustments of operating parameters may be required.
- Total Nitrogen and Phosphorous concentrations are sensitive to change or upset conditions, but will naturally return to normal after some period.
- $CBOD_5$ are less sensitive for changes in hydraulic loading.
- Normal hourly and daily variations of influent flow rates and mass-loading rates have little or no effect on effluent water quality.

REFERENCES

U.S.EPA, (1980), "*Onsite Wastewater Treatment and Disposal System Design Manua*l", EPA/625/1-80-012.

Wistrom, A.O. and M. Matsumoto, (1999), "*Evaluation of MicroSepTec EnviroServer Residential Wastewater Treatment System*", Department of Chemical and Environmental Engineering, University of California, Riverside.

Ventura Regional Sanitation District, (2001), "*Septic Tank Nutrient Removal Project*", California State Water Resources Control Board Agreement No. 0-047-454-0.

Metcalf & Eddy, (1991), "*Wastewater Engineering: Treatment, disposal, and reuse"*, Eds. Tchobanoglous, G.T.and Burton, F.L., 3rd Ed., NewYork, McGraw-Hill.