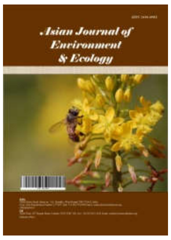

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Bio-Tower Application for Improvement of a Decentralized Waste Water Treatment System for Residential Applications–Reduction of Nonpoint Source Pollution by Nitrogen

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Authors' contributions

This work was carried out in collaboration between both authors. Author KD wrote the first draft of the manuscript and approved the final manuscript.

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ABSTRACT

The application of decentralized wastewater treatment system, also known as septic system is very common in suburban and rural areas with no access to centralized sewage treatment plants. Minimizing water pollution and the effects on wildlife and humans is of specific concern in rural and urban areas.
A packed bio-tower addition to a 1000 gallon septic tank was tested under pilot conditions using municipal residential sewage. The septic tank packed bio-tower pilot system is able to reduce the NH_3-N influent level of 16.5 mg/l to 24.0 mg/l by 77.3% to 96.7% at influent flow levels between1060 l/d (280 gal/d) and 3997 l/d (1056 gal/d).
Biochemical oxygen demand levels reduction was 97.0% from 280 mg/l to 8.5 mg/l. for a flow rate of 1060 l/d (280 gal/d).
Research showed that a bio-tower addition to a septic system has the potential to improve the systems overall performance.

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Keywords: Wastewater treatment; bioreactor; contaminant removal; COD; BOD; nitrogen.

1. INTRODUCTION

One of the most significant changes facing our world today and in the future pertains to clean water. Without clean water, life is not sustainable. Water pollution affects local wildlife and us humans equally and we all should work on minimizing and perhaps eliminating waste and water pollution [1].

Growing rural and suburban development is one of the biggest challenge in sustaining the natural beauty and water quality with increased waste production. The application of decentralized wastewater treatment system, also known as septic system is very common in suburban and rural areas with no access to centralized sewage treatment plants. This puts a burden on local governments on how to protect the environment from wastewater produced by decentralized wastewater treatment systems in these areas. [2].

Wastewater consists of approximately 99.9% water and 0.1% waste, which is comprised of organic and inorganic matter, dissolved and suspended solids, and microorganisms [1,3].

According to the Environmental Protection Agency (EPA) one of every five households operates a decentralized wastewater treatment system in the US [4].

Nonpoint source pollution by nitrogen and phosphorous from decentralized wastewater treatment systems runoff and failing systems is today a widespread and challenging environmental problem in America [5,6]. Human waste from underperforming decentralized wastewater treatment systems might contribute to the pollution of nearby water bodies and can cause nitrification and increase in phosphorus components, which can increase algae blooms mostly during warm summer month in the water body and can affect the environment, public health and the economy [2,4].

Nitrogen, in its nitrate form, is limited to 10 milligrams/liter in drinking water. Higher levels can cause health risks to human and livestock [7]. However, nitrate levels of unpolluted water are below 1 milligram/liter [8]. Higher nitrate levels can cause ecological damage in lakes and rivers and wildlife before it reaches the toxic effect for humans and livestock. Therefore, today's communities need to take precautions to protect waterbodies from contaminations to minimize their ecological impact [9].

Currently there is no economical technology available to upgrade and enhance decentralized wastewater treatment systems in urban developments that are not connected to waste water treatment systems. Improving existing and new septic systems performances could minimize the effluent loading of decentralized wastewater treatment systems. One option could be the application of a small bio-tower or sometimes known as trickling filter to a decentralized wastewater treatment systems. A trickling filter is one of the main type of biological control units in the secondary treatment process at waste water treatment plants [10,11]. It consists of a round tank structure that contains usually engineered growth media with a high surface area [12]. Rock, slag and wood chips was used as a common growth media in the past in trickling filters. Today, materials such as Polyvinyl Chloride (PVC), Polypropylene (PP) with a defined specific surface area between 90.0 to 226.0 m^2/m^3 (27.4 to 68.9 ft^2/ft^3) are utilized [13,14]. A distribution system spreads the wastewater equally over a biofilm covered growth media. The wastewater then trickles over the medium and is collected at the bottom of the bio-tower and forwarded to the tertiary treatment process [15].

Trickling filters applied at waste water treatment processes traditionally remove organic matter by heterotrophic bacteria, this process can be successfully combined with a nitrification process. Nitrification is the sequential reaction from ammonium over nitrite to nitrate, carried out by the autotrophic nitrosomonas and nitrobacter bacteria [16]. In the upper portion of the bio-tower heterotrophic bacteria outgrow the nitrifying species. As soon as the organic matter in the waste water is subsequently decreased below a threshold concentration of approximately 20 mg/l soluble 5-day Biochemical Oxygen Demand (BOD), the nitrifying bacteria can compete and initiate nitrification [17,18,19,20,21].

Past studies provide good empirical data for setting up combined carbon oxidation and nitrification trickling filters. Choosing the right BOD-loading is of primary importance to achieve proper nitrification, whereas a low BOD-loading generally means good nitrification. The United States Environmental Protection Agency has recommended organic loading rates per unit volume for different filter media [17], which are comparable with data Richards and Parker found earlier [22].

According to the Unites States Environmental Protection Agency (USEPA), temperature highly influences the nitrification and must be set in a temperature range between 4 and 45 degree Celsius. Even though there is no consistent data that quantifies the effect of different temperatures on nitrification, satisfactory nitrification occurs in the range from 15 to 25°C (50°F to 77°F). The pH-value of the wastewater should range from 6.5 to 8.0 to ensure process stability [16]. The rate of dissolved oxygen usually does not limit combined nitrification and carbon oxidation processes with natural air draught, as they are typically operating with low organic loading rates. Recirculation of the effluent and therefore, increasing hydraulic loading can improve nitrification rates above 50% for moderate or high temperatures. Recirculation has also a quite pronounced effect on removal of organic matter for deep bio filters, as in a bio-tower [22,23,24]. A recent study shows that a bio-tower can remove volatile organic compounds, which would harm humans and the environment [25]. The research project evaluated the NH_3-N reduction potential applying a recirculating bio-tower to a septic tank pilot system.

2. METHODOLOGY

The methodology section describes the set-up, installation, and methods used for the pilot study of the Septic Tank Packed Bio-tower (STPB) pilot system at the Village of Minoa's Cleanwater Educational Research Facility (CERF) for the investigation of nonpoint source pollution by nitrogen.

2.1 STPB Pilot System Set-Up

At the Minoa Waste Water Treatment plant (WWTP) approximately 950,000 l/d of Municipal Residential Sewage (MRS), which contains no industry effluents, is directed from the influent structure into a Primary Clarifier (PC). After PC treatment, half of this flow is directed to a Constructed Wetland (CW), the other half is discharged into an Influent Box (IB) together with the CW effluent.

As shown in Fig. 1, a portion of the MRS entering the PC from the influent structure is forwarded to the STBP pilot system, operating in bypass mode. The effluent from the STPB pilot system is discharged back into the influent structure influent stream. This operation setup assured that the MRS used for the STPB pilot system is contained in the WWTP operation.

The treated MRS from the PC and CW and mixes in the IB and is then forwarded into a Trickling Filter (TF). After the TF treatment, the treated WW passes through a Secondary Clarifier (SC) and a Disinfection Unit (DU) before it is discharged into a stream [19,27].

2.2 STPB Pilot System Design

A STPB pilot system was designed and installed according to Fig. 2 for testing the removal of compounds contained in the MRS. The STPD was installed at CERF located at the Village of Minoa wastewater treatment plant. The STPD system including its supporting infrastructure was installed by the Minoa Department of Public works (DPW) and CERF personnel according to local regulations.

The PBT system consists of a 1000 gallon High Density Polyethylene (HDPE) septic tank (1) able to hold 3747 liter (990 gal.) of MRS. The bio-tower (2) was manufactured from a 18 inch (457 mm) corrugated pipe and had a length of 1525 mm (5 ft).

The Bio-tower contains two sections of Bentwood CF-1900 Polyvinyl chloride (PVC) bacteria growth media (3) used for BOD and Chemical Oxygen Demand (COD) reduction and nitrification. The Growth Media Packing (GMP) is Ultraviolet light (UV) protected and resistant to rot, fungi, bacteria decay, acids and alkalis commonly found in WW and has a surface area of 157 m^2/m^3 (48 ft^2/ft^3) [28].

The two GMP section have a height of 608 mm (2 ft) and each GMP has a specific surface area of 15.75 m^2 (169.54 ft^2). The first GMP section support is 100 mm (4 in) above the bottom of the bio-tower (2) and the second GMP section support is 100 mm (4 in) above the first GMP. The 100 mm (4 in) gap between the GMP sections and the bottom of the bio-tower allows aeration through four 90-degree spaced air distributors (8) manufactured from 38.1 mm (1.5 in) inside diameter Schedule 40 PVC pipes and fittings.

The MRS liquid in the septic tank (1) is pumped with a 0.375 kW (0.5 hp) pump (5) at a constant rate of 37.85 l/min (10 gal/min) through a Schedule 40 (PVC) suction pipe (4) and a transfer pipe with 25.4 mm (0.5 in) inside diameter into a PVC distributer (7) containing 5.0 mm (0.197 in) holes. Valve (11) allows fine adjusting the flow to the bio-tower.

For all PVC piping connections to and from the STBP, PVC bulk tank fittings are used. Bulk tank fittings allow the attachment and sealing of pipes of any size through a variety of materials.

2.3 STPB Start-Up

The STPD pilot system was started up by first filling the STPB pilot system septic tank with MRS. The MRS suspension is then pumped with pump (5) at a constant rate of 37.85 l/min (10 gal/min) through suction pipe (4) and transfer pipe (8) into the distributer (7). From the Distributor the MRS trickles the liquid onto the Brentwood CF-1900 GMP (3). As the liquid flows down through the first 608 mm (2 ft) of the top GMP it is distributed horizontal and vertical and spread throughout the entire GMP. This results in an equal distribution of the suspension through the remaining 608 mm (2 ft) of the top GMP section. As the suspension is exiting the second GMP packing, it trickles back into the septic tank (2) and mixes with the MRS in the septic tank.

The PBT system continued to operate in this way for 2 weeks to establish the needed bacterial colonies on the GMP. Approximately 1332 l/d (352 gal/d) of MRS was added continuously to the STPD. The initial testing started with the same feed rate of MRS used for the start-up.

2.4 Testing and Recording

500 ml Nalgene bottles were used to collect the MRS influent and effluent samples of the STPB. The samples were stored in a cold room at 4.0°C (39.2°F) before, during and between testing. Testing was conducted in the first 24 hours after taking the sample.

A HACH DR900 Spectrophotometer and a HACH DRB200 Reactor was used for analyzing the exact concentration of Ammonia Nitrogen NH_3-N followed HACH Method 10031 [29] for NH_3-N using HACH-TNT Reagent Set (0.4-50.0mg/L).

Final samples at the end of the testing period for BOD/BSB and NH_3-N were sent to a certified laboratory for analyzation, using method SM 5210 B Biochemical Oxygen Demand (BOD) [30].

3. RESULTS AND DISCUSSION

After STPD pilot system operated for two weeks under a MSR influent flow rate of 1332 l/d (352 gal/d) testing started. Fig. 3 shows the testing results over a 50-day period on NH_3-N removal of the STPD pilot system.

Testing on Day 1 showed an NH_3-N influent of 16.5 mg/l is reduced by 96.7% to 0.5 mg/l. After samples were taken, the influent flow to the septic tank was increased from 1332 l/d (352 gal/d) to 1999 l/d (528 gal/d) and samples taken after 48-hours (Day 3) and 96-hours (Day 5). For both tests, the influent NH_3-N level was 16.5 mg/l. The effluent NH_3-N level was 0.9 mg/l for the Day 3 sample and 0.7 mg/l for the Day 5 sample, which correlates to a reduction of NH_3-N of 94.5% and 95.8% respectively.

After sampling on Day 5 the influent flow to the septic tank is increased from 1999 l/d (528 gal/d) to 3997 l/d (1056 gal/d). Samples were taken after 120-hours of operation on Day 10. The influent NH_3-N level on day 10 was 15.0 mg/l. The effluent NH_3-N level was 3.4 mg/l, which correlates to a reduction of NH_3-N of 77.3%.

After sampling on Day 10 the influent flow to the septic tank is decreased from 3997 l/d (1056 gal/d) to 1999 l/d (528 gal/d) and the STPD is operated for another 5 days or 120-hours before the next samples are taken on Day 15. On Day 15, the measured NH_3-N influent level was 18 mg/l which has been reduced by the STPD by 94.4% to an effluent NH_3-N level of 1.0 mg/l.

The STPD system continued to operate for another 3 weeks under the flow of 1999 l/d (528 gal/d) for reliability purpose before another testing was done on Day 37. The measured NH_3-N influent level on day 37 was 24 mg/l, which has been reduced by the STPD by 91.7% to an effluent NH_3-N level of 2.0 mg/l. The system was operated for another 3 days, and had then be stopped due a pump failure on Day 40. After repairs and additional cleaning work, the system started operating on Day 42 for another 8 days under a influent flow of 1060 l/d (280 gal/d) to the STPD. Testing conducted on Day 50 revealed that the NH_3-N influent level was 21 mg/l, which has been reduced by the STPD by 95.7% to an effluent NH_3-N level of 0.9 mg/l. In addition Biochemical Oxygen Demand (BOD) influent and effluent was tested at a certified laboratory which showed that the BOD influent was 280 mg/l and the STPPD BOD effluent was 8.5 mg/l which is below the 25 mg/l allowable effluent discharge limit of the Waste water treatment plant.

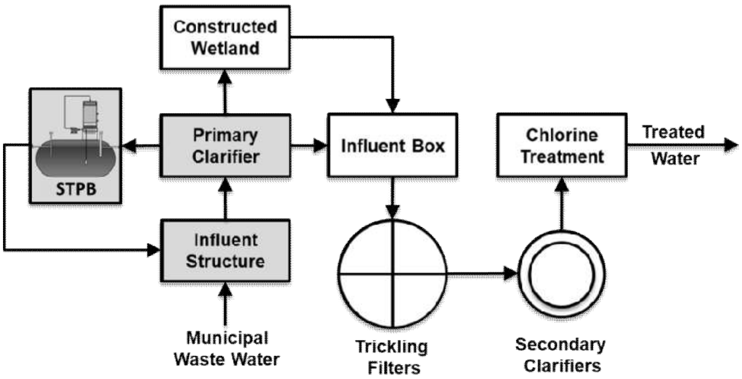

Fig. 1. Septic Tank Packed Bio-tower Pilot System Process Flow Sketch [26]

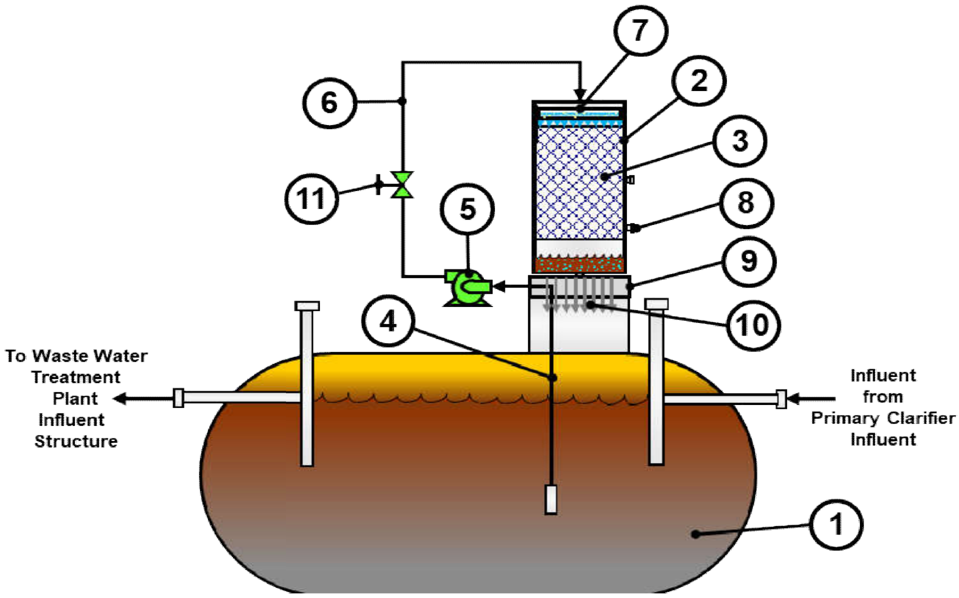

Fig. 2. Septic Tank Packed Bio-tower Pilot System, (1) Septic tank, (2) Bio-tower, (3) Growth media, (4) Suction line, (5) Recirculating Pump, (6) Transfer Line, (7) Distributor, (8) Aeration, (9) Manhole, (10) Bio-tower effluent, (11) Flow adjustment valve [23]

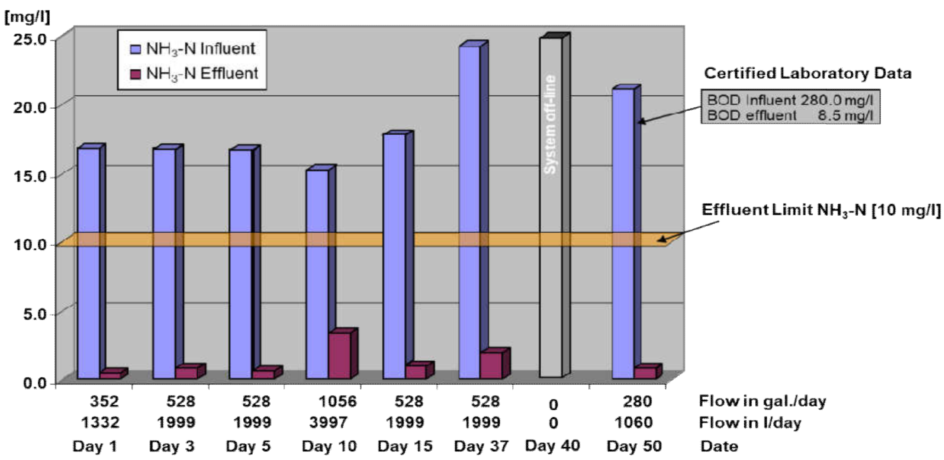

Fig. 3. Septic Tank Packed Bio-tower Pilot System NH3-N removal rate

4. CONCLUSION

The application of decentralized wastewater treatment system, also known as septic system is very common in suburban and rural areas with no access to centralized sewage treatment plants. Minimizing water pollution and the effects on wildlife and humans is of concern in rural and urban areas. The presented with STPB pilot system using MRS showed that a bio-tower addition to a septic tank holding 3747 l (990gal.) of MRS is able to reduce the NH_3-N of 16.5 mg/l to 18.0 mg/l contain in the MRS influent between 94.4% and 96.7% to an effluent level of 0.5 mg/l. to 1.0 mg/l for influent flows of 1332 l/d (352 gal/d) to 1999 l/d (528 gal/d).

For higher NH_3-N level in the influent of up to 24 mg/l a reduction of 91.7% in the effluent to 2.0 mg/l could be realized for a flow rate of 1999 l/d (528 gal/d).

For a high flowrate of 3997 l/d (1056 gal/d) with and influent NH_3-N level of 15.0 mg/l the effluent NH_3-N level was reduced by 77.3% to 3.4 mg/l.

For a low flow rate of 1060 l/d (280 gal/d) with an NH_3-N influent level of 21 mg/l, the effluent NH_3-N level was 0.9 mg/l or a reduction of 95.7%. In addition, the STPB showed its ability to reduce the BCOD influent by 97.0% from 280 mg/l to 8.5 mg/l.

For both, the NH_3-N and BCOD the STPB was able to reduce the effluent below the WWTP discharge limits of 25mg/l for BOD and 10 mg/l for the NH_3-N.

A bio-tower addition to a septic system has the potential to improve the overall performance of a septic system.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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