Original Research Article

Enhancement of a Decentralized Wastewater Treatment System by Applying a Bio-tower - A Project for Improving our Environmental Footprint

ABSTRACT

To investigate if decentralized wastewater treatment systems impact on the environment performance can be improved, a Field Bio-tower Tank Septic system was designed, installed on an existing 1,500-gal (5678 l) decentralized wastewater treatment system. The system was started up during a 14-day start-up phase, followed by a 130-day test phase. The system was operated at an average hydraulic retention time of 16.7 days based on a 90 gal (204.4 l) daily influent wastewater flow.

The systems recirculation flow for the bio-tower was 22.6 l/min (6 gal/min) for the start-up phase and 40.0 l/min (10.6 gal/min) for the test period with a corresponding recirculation of the entire septic tank from 5.7 to 10.1 times a day respectively.

During the testing period a daily average temperature of 19.3°C (66.7°F) and an average rainfall of 5 l/m² was observed. The FBST system operated at an average influent pH level and temperature of 8.6 and 22.0°C. The average effluent pH and temperature was 8.5 of 20.9°C.

The installed system reduced on average the influent TS from 79151 mg/l to 43021 mg/l and shoed an average reduction of the TDS from 36424 mg/l to 21965 mf/l. The TSS and VSS was reduced on average from 94.1 mg/l to 69.9 mg/l and 89.0 mg/l to 64.9 mg/l.

NH_3-N content was reduced from 57.5 mg/l in the influent to 53.4 mg/l in the effluent. The average BOD and COD was reduced from the average influent value of 88.2 mg/l and 318.2 mg/l to 66.8 mg/l and 256.2 mg/l respectively. However, at the end of the 130-day test period BOD and COD values were the lowest at 15.5 mg/l and 56.0 mg/l respectively, indicating bacteria cultures are well established and the system operation of the FBTS system is mostly constant.

This research showed that the FBST system can improve operations of a DWWTS system significantly reducing the effluent load over 10 times compared to the influent load of the system.

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Keywords: Biotower, decentralized wastewater treatment, contaminants, effluent, septic system, sewage, wastewater, wastewater treatment

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1. INTRODUCTION

One of the most significant challenges facing our world 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].

Sustaining the natural beauty and quality of our water bodies is today’s biggest challenge with ever growing urban and suburban developments. Many new urban and suburban developments are too far away from existing wastewater treatment plants (WWTP) fostering the use of Decentralized Wastewater Treatment Systems (DWWTS), also known as Septic Tank Systems (STS). Urban and suburban governments are faced with the burden decentralized water treatment systems and how to protect waterbodies in the affected areas [2]

The invention of the STS is credited to Frenchman Jean-Louis Mouras, who constructed during the 1860s a system comprised of a masonry tank into which the sewage of his dwelling in Vesoul, France is discharged. The tank was opened after several dozen years and found free of solids. Mouras eventually got a patent of his invention on September 2, 1881 with patent No.: 144.904. It is believed that the septic tank was initially introduced to the United States in 1883, and by the late 1880's, septic tanks similar in concept to those used today were in common use. Even now, over 170 years later, septic tanks still represent a major domestic wastewater treatment option in the United States of America, with little changes to the original design [3, 4, 5].

A DWWTS today, consists of a tank with an influent and effluent pile. Liquid containing the contaminants enter the system through a influent pipe settle in the tank. Solids are disintegrated by the bacteria consortium in the system. The liquids discharge as effluent and percolates through a drain field downwards till it reaches the ground water table. Contaminants that are small enough can potentially reach aquifers as they make its way through the drain field soil layers [6,7].

The Unites States (U.S.) Environmental Protection Agency (EPA) estimates that today, one of every five households operates a DWWTS [8]. 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 growth mostly during warm summer month in the water body and can affect the environment, public health and the economy [9,10].

Maintaining DWWTS systems in important to ensure satisfactory operation. Underperforming septic systems are caused by not properly operating the system by: (i) not inspecting the system components and removing the sludge every 3 years, (ii) not using conserving and using water efficiently, (iii) not disposing waste properly such as prior removing grease and oil, before it enters the septic system, and (iv) maintain the DWWTS drain field such as parking or driving on a drain field, and or planting trees close to a drain field, and or direct excess water from sup pumps, roofs and run-off water onto the drain field [11].

Wastewater in a domestic setting can contain many different potential pollutants which cause a risk to aquifers. These pollutants can be chemicals, household detergents from laundry and dishwashing, Phosphorous (P), Nitrogen (N), Ammonia (NH_4-N), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Suspended Solids (SS), and pharmaceutical compounds due to medicine use of residents [11-16].

Prior research with a 1000-gallon research pilot system a WWTP included a septic system tank (1000 gal) with an addition of a small recirculating bio tower (18 in diameter 4 ft. tall). The influent water to the septic tank was municipal wastewater with a BOD influent of 280 mg/l and NH3-N around 16mg/l. Results have shown that the effluent of the modified septic tank system at an influent flow between 280 gal/d and 1056 gal/day are below 10 mg/l for BOD and 1 mg/l for NH3-N [17].

At the laboratory scale a study by Dölle, Qin and Wang and shows that a bench type laboratory type recirculating bio-tower can reduce in 8 hours, 70%-80% COD, over 90% TP and over 80% of NH3-N contained in wastewater [13].

A large pilot scale study by Dölle & Qin showed that pilot scale bio-tower system with commercial growth media is able to reduce COD contained in wastewater between is between 63.4% and 84.8% The influent NH_3-N reduction achieved was between 99.8% and

91.8% having a recirculation flow rate flow of 75.7 l/min (20 gal/min) and a feed rate of 7,520 l/d (2000 gal/d) and 90,850 l/d (24,000 gal/d) [18].

A recent laboratory study by Dölle and Lex using a small-scale laboratory septic system [19] and applying a small bio-towers revealed that at a hydraulic retention rate (HRT) of 5, 10 and 20 days, COD reduction was between 32% and 74.6% and Total Solids (TS) and Total Suspended Solids (TSS) reduction achieved was between 44.1% and 75.9% and 58.6 to 75.9% respectively [19].

Preserving clean water is everybody's concern and responsibility. To field test, the bio-tower approach on an actual DWWTS, Rap-Shaw Club Inc., a hunting and fishing club founded in the late 1800's and located in the New York Adirondack State Park on Williams Island at the Stillwater Reservoir in Herkimer County was approached. The Board of Directors of Rap-Shaw Club Inc. decided to be environmentally proactive and allow the private funded research project to investigate the possible improvement on their DWWT.

Prior to performing the research, a jurisdictional inquiry form with the Adirondack Park Agency (APA) was filed. After no concerns were found by the APA the research has been conducted at the clubs 1,500 gal. (5678 l) septic wastewater treatment system, to investigate if the effluent loading to the drain field and the overall system performance can be improved.

2. MATERIAL AND METHODS

The material and methods section describes the system, procedures, and materials used for the research project on a 1,500-gallon (5678 l) septic system located and installed at the Rap-Shaw Camp site. The existing septic system itself has not been modified or changed for the research work. The bio-tower, manufactured from two 55-gallon (208 l) PVC drum was installed on top of the septic tank manhole located on the septic tanks influent side. After conclusion of the research project the bio-tower has be removed and the septic system operates in its original setting.

2.1. Location

2.1.1 Williams Island

A sketch of the Rap-Shaw Club Inc. Williams Island property with approximated building location, fresh water, and wastewater utility locations as shown in Figure 1.

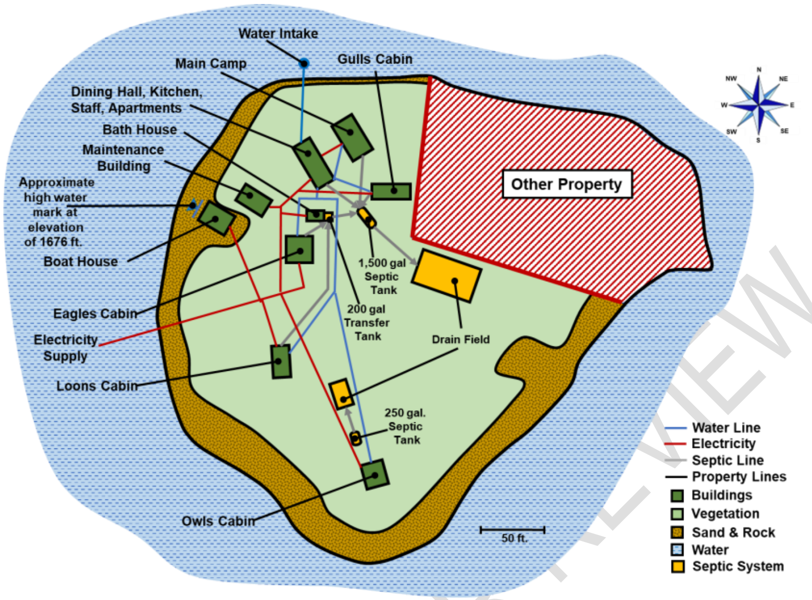

Fig. 1. Rap-Shaw Club Williams Island Property Sketch [20]

Williams Island is located at the Stillwater Reservoir in the town of Webb in Herkimer County.

The 6,700-acre (27.11 km^2) Stillwater reservoir is a man-made lake in the western Adirondacks New York State Park and provides multiple recreational possibilities which include remote wilderness, canoeing, camping, boating, fishing, hunting snowmobiling, and cross-country skiing activities [21]. The reservoir was built in 1885 and enlarged to its today's size in 1924 to regulate the flow from Beaver and Black River for flood control, power production and welfare of the general public. The reservoir contains a usable capacity of 4,623 million ft^3 (130.9 million m^3) for release between elevations 1,650.3 ft (503 m) and 1,679.3 ft (511.8 m) at the top of 24-inch flashboards, which are in place throughout the year. The lowest fill level of 100 million ft^3 is at an elevation of 1642.3 ft (500.5 m) which is the lowest outlet measured at the gate sill and is not ordinarily available for release [22].

The Rap-Shaw Club Inc. property on Williams Island is approximate 3.0 acres (12,140 m^2). The other property contains two private cabins that are not part of the Rap-Shaw Club.

The club has six cabins, one bathhouse, one maintenance building and on boathouse located on Williams Island. Main Camp built in 1920 and has a size of approximate 1,265 ft^2, (117.5 m^2). Gulls and Loons Camp built in 1920 and have a size of approximate 576 ft^2 (53.5 m^2), and Eagles Camp built in 1998 and has a size of approximate 752 ft^2 (69.9 m^2). Owls Camp built in 1940 and has a size of approximate 432 ft^2 (40.1 m^2). The Dining Hall built in 1920 has a size of approximate 2,226 ft^2 (1206.8 m^2). and contains two staff apartments, the kitchen, laundry facility and the fresh water supply system.

All wastewater produced at Williams Island on the Rap-Shaw Club Inc. property is treated with a septic system. Wastewater from Eagles Camp toilet and sink is treated with an approximately 250-gallon (946 l) septic tank and discharges into a small drain field. Wastewater from Main, Gulls, and Loons Camp, including the Dining Hall and the Bathhouse is treated with a 1,500-gallon (5678 l) septic tank. The effluent is discharged into a large drain field. Main, Gulls, and Loons Camp have shared bathroom facilities with sink and toilet.

The two apartments on the second floor of the Dining Halls, Eagles Camp and the Bathhouse have full bathrooms facilities. The needed freshwater is supplied by the Rap-Shaw Clubs own water supply system that filters water from the Stillwater Reservoir for utility use to drinking water quality. The water supply facility is inspected regularly by the New York State Health Department.

Electricity supply is brought to Williams Island from the mainland by an underwater power line.

Portable Water (PW) is produced by a Water Treatment System (WTS) shown in Figure 2, which produces the needed drinking water for up to 9.2 gpm (34.8 l/min) for the Rap-Shaw Club operation from the approximately 6,700 acre (21,1 km^2) large Stillwater reservoir. The WTS is designed approved to applicable regulations of the New York State (NYS) Department of Health (DOH) and applicable county and local regulations applicable to treat water from natural sources for microorganisms, bacteria, toxic chemicals, viruses and fecal matter.

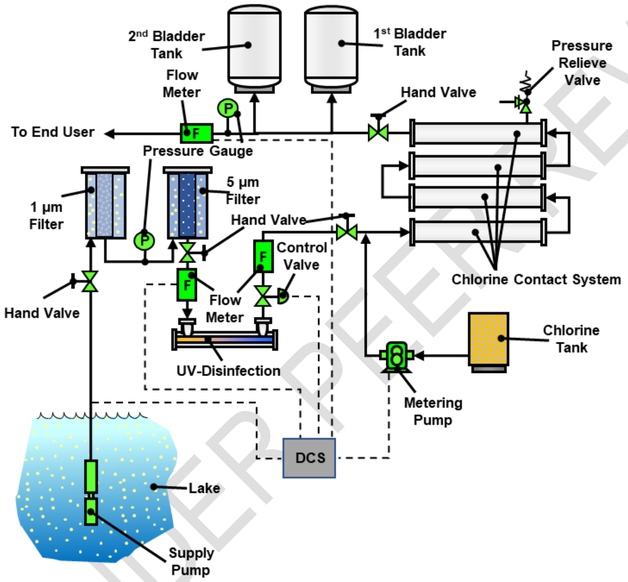

Fig. 2. System for the production of portable water [23]

The water is pumped from the Stillwater Reservoir approximately 300 ft (91.4 m) from a depth of approximately 60ft (18.3 m) to the WTS System using a Bruiser Model 12SB07 submersible pump with a .75 hp (0.56 kW) electro motor. The water is pumped through two Harmsco Model WB 90SC-2 filter housing, one equipped with a Harmsco PP-HC/90-1 1µm filter cartridge, followed by an Harmsco HC/90-AC-5 5µm activated carbon filter cartridge. The filtered water is treated with a Hallett 3011 Ultraviolet (UV) system, providing a UV light with an intensity of $40mJ/cm^2$ to the filtered water. A dosing pump is adding chlorine to the treated water to achive between 0.2 mg/l and 4 mg/l free residual chlorine, followed by a minimum of 15 minutes of chlorine contact time through a series of four 12-inch (304 mm), 10-foot (3.0 m) long Polyvinyl Chloride (PVC) pressurized pipes connected in series. The treated PW is kept at a pressure of 30 to 40 psi with two pneumatic pressure (bladder) tanks. The WTS is automatically operated and controlled using a digital control System (DCS).

2.2. Field Bio-tower Septic Tank System

A Field Bio-tower Septic (FBTS) system was designed and installed according to Figure 3. At the Rap-Shaw site on Williams Island located at the Stillwater reservoir.

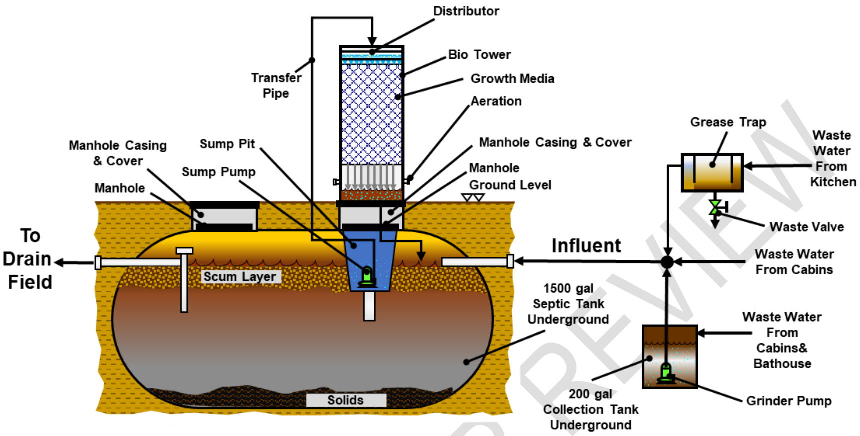

Fig. 3. Field Bio-tower Tank Septic (FBTS) System [25]

The bio-tower was installed on top of the septic tank manhole located at the influent side of the septic tank. The influent into the FBTS system consists of three fractions: First, WW from the kitchen is gravity fed to the FBTS and has to pass a grease trap for oil and grease removal before entering the septic tank. In addition, biosolids in the kitchen WW, like large cooking scraps, and organic components are removed by strainers and composted. Second, WW from the cabin sink and toilets are gravity fed direct into the FBTS. Third Waste water from cabins and the bathhouse is collected in a 250 gallon (946 l) sump pit and pumped automatically with a Zoller 0.75 hp (0.55 kW) grinder pump into the FBTS system intermediate when the WW level in the sump pit reached the maximum level set at 180 gal (681 l).

All Polyvinyl Chloride (PVC) pipe, fitting material, PVC primer and clear cement for fusing PVC part together and was purchased in a local hardware store. PVC parts were manufactured from Charlotte Pipe and Foundry Company. PVC primer and clear cement used was manufactured from Oatey® company.

The FBTS system consists of an existing 1,500-gallon (5678 l) fiber glass reinforced septic tank. The 6 ft (1.8 m) high bio-tower was made of made out of two 55-gallon (208 l) PVC drums containing the growth media and a half 55-gallon drum serving as the drip pan of the bio-tower. The section of the bio-tower containing the growth media was supported with with brick blocks in the dripping pan. Bentwood CF-1900 PVC Bacteria Growth Media Packaging (BGMP) was used in the two bio-tower (3). BGMP is used for BOD and Chemical Oxygen Demand (COD) reduction and nitrification and is Ultraviolet light (UV) protected and resistant to rot, fungi, bacteria decay, acids and alkalis commonly found in WW. The surface area of the BGMP is 157 m²/m³ (48 ft²/ft³) according to manufactures specification [24].

The two BGMP sections were cut to a height of 24-inch (610 mm) first, section and 34-inch (864 mm) for the second section (bottom section). Both sections have a diameter of 20-inch

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(508 mm) and were placed into the 55-gallon drums. The GMP in FBTS system has a specific surface area of 46.9 m^2 (504.8 ft^2). The first GMP section support is 100 mm (4 in) above the bottom of the second BGMP section in the bio-tower. The second BGMP section support is 1 ft (304 mm) above the drip pan bottom. The drip pan contains four 90-degree spaced air distributors manufactured from 38.1 mm (1.5 in) inside diameter Schedule 40 PVC pipes and fitting, allowing aeration from the bottom of the tower.

The BGMP features alternating corrugated flow channels at a 60° angle that allows up to 720 vertical distributions per 1 ft (304 mm) [18, 24]. As the WW influent flows down through the channels of the BGMP it is redistributed and spread throughout the whole BGMP.

Figure 3., shows that after the liquid passes vertically the first section with a height of 2 ft. (610 mm) it has been distributed equally throughout the whole BGMP area. The remaining 34-inch (864 mm) second BGMP section has then an equally WW distribution, assuming the WW has been distributed equally in the first top 2 ft section of the BGMP. In addition, to the WW distribution, the CF-1900 growth media allows a uniform horizontal and vertical air flow distribution throughout the BGMP provided by the 4 aeration distributors located on the bottom of the bio-tower [18, 24].

Fig. 4. Bio-tower CF-1900 water Distribution [26]

The manhole of the septic tank has a 30-gallon (113 l) sump pit with a 1 ft (304 mm) extension manufactured from a 4-inch (102 mm) inside diameter Schedule 40 PVC pipe, allowing the septic tank influent to enter the sump pit. The sump pit influent is pumped with a 0.375 kW (0.5 hp) Superior Pump Model 91250 thermoplastic submersible utility pump at a constant rate of 22.6 l/min (6 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 manufactured from a 5-gallon (19 l) PVC pail with 20 holes arranged in the circumference and the bottom to equally distribute the WW flow. The water level in the distributor is maintained at an approximate height of 8-inch (200 mm). The WW influent that is pumped into the distributor is tricked on the BGMP and flows through the 2 BGMP section till it is collected in the drip pan. From the drip pan it flows back into the septic tank through a from 38.1 mm (1.5 in) inside diameter Schedule 40 PVC pipe 90-degree away from the WW influent line. The transfer pipe has a sample valve installed for taking influent samples of the WW prior to entering the distributor. The effluent of the FBTS flows to a drain field located 20 yards away from the FBTS for final treatment.

Figure 5., shows the self-built FBTS system as described above installed on top of the1,500-gallon (5678 l) fiber glass reinforced septic tank at the beginning of the testing period.

Fig. 5. Field Bio-tower Septic (FBTS) System Installation [27]

2.3. Influent Waste Water

The Influent Waste Water (IWW) into the FTBS consists of three fractions. The influent into the FBTS system consists of three fractions: First, WW from the kitchen is gravity fed to the FBTS and has to pass a grease trap for oil and grease removal before entering the septic tank. In addition, biosolids in the kitchen WW, like large cooking scraps, and organic components are removed by strainers and composted. Second, WW from the cabin sink and toilets are gravity fed direct into the FBTS. Third WW from cabins and the bathhouse is collected in a 250-gallon (946 l) sump pit and pumped automatically with a grinder pump into the FBTS system when the WW level in the sump pit reached the maximum set level.

2.4. Laboratory Testing Procedures

For determining the Chemical Oxygen Demand (COD), Total Phosphorous (TP) and Ammonia Nitrogen (NH_3-N) a HACH DR1900 and a HACH DRB200 Reactor was used to analyze the samples. HACH 8000 Method was used for analyzing COD using HACH TNT plus® Vial Test (3-150.0mg/L) [28], HACH Method 10127 [29] for TP using HACH-TNT Reagent Set (1-100.0mg/L), and HACH Method 10031 [30] for NH_3-N using HACH-TNT Reagent Set (0.4-50.0mg/L).

The TS was measured in triplicate. Each test sample was measured using a 300 ml aluminum sample container, which was marked and weighted accordingly. Then approximately 200 ml to 220 ml of the prepared substrate was added to each of the three corresponding aluminum sample containers prepared for the given test sample. Weighting of the sample containers followed, before they were placed in a ~105°C oven to dry for 48 hours to evaporate the moisture, following TAPPI test method T 240 om-07-“Consistency (concentration) of pulp suspensions"[31]. After drying, the samples were weight again to determine their dry weight measurement. The remaining solids were the TS content of the substrate.

For measuring, the TSS the Cole Parmer Total Suspended Solids Method and Procedure was used [32]. Each test was performed in triplicate. The sample was filtered using a 45 µm pore size glass fiber fabric filter (HACH, Be Right, grade: MGA, 47 mm). The solids which were retained on the filter and dried at 105°C gave then the measurement for the TSS [24].

Volatile suspended solids (VSS) based on TSS are obtained by igniting the TS content remaining on the glass fiber fabric filter pad in ceramic crucibles at 525°C following TAPPI test method T211 om-02, Ash in wood, pulp, paper and paperboard: Combustion at 525°C [33]. VSS based on TSS was calculated by subtracting the remaining solids (ash) on the glass fiber fabric filter pad after ignition from the obtained TSS.

Fixed Suspended Solids (FSS), the inorganic particles such as undissolved salt crystals, silt particles, sand, etc. that are suspended in the liquid and made it through the 45 µm pore size glass fiber fabric filter pad glass fiber filter, was calculated by subtracting the VSS value from the TSS value.

ORP was measured with a handheld Hanna OPR meter.

Temperature and pH measurements were conducted using a portable Milwaukee MW102 pH/temperature meter.

2.5. Start-Up of the Biotower Septic Tank Field System

Prior to installing the FBTS system at the research site, the existing septic tank was pumped and the scum layer removed. The septic tank was filled with water to prevent damage and caving and was ready to operate again. After the FBTS system was installed on top of the septic tank manhole located at the influent side of the septic tank the system was started up and a 14-day start up phase was initiated to establish a biofilm on the GMP.

During the entire start-up time of the FBTS system the outside temperature was between 8.4±0.5°C (47.1±0.9°F) and 31.9±0.5°C (89.4±0.9°F) with the average temperature at 24.2±0.5°C °C (75.6 ±0.9°F). The recirculating pump ran at a volumetric rate of 22.6 l/min (6 gal/min) pumping the WW contained in the septic tank to the distributer, from which it trickled through the BGMP in the bio-tower. The recirculation flow represented a Septic Tank Recirculation (STR) of 8.76 times per day.

After the WW passes vertically the first 2-foot (304 mm) of the 5-foot 8-innch (1474 mm) BGMP media, it can be assumed that the liquid has been distributed equally throughout the whole BGMP area. The remaining 3 foot 8-inch (1170 mm) of the BGMP section has then an equal WW distribution, assuming the WW has been distributed equally in the first top 2 ft section of the BGMP. In addition, to the WW distribution, the CF-1900 growth media allows a uniform horizontal and vertical air flow distribution throughout the GMP provided by the 4 air distributors on the bottom of the bio-tower, allowing optimal bacteria growth conditions by liquid and air supply [24]. As the WW exits the BGMP packing it is collected on the bottom of the FBTS system and then transferred back into the septic tank by gravity.

The same amount of influent flowing into the septic tank is discharged at the effluent site of the septic tank and transferred to the leach field for final treatment in the drain field.

3. RESULTS AND DISCUSSION

The following chapter summarizes and compares the degradation processes and effluent qualities of the FBTS systems during an over 3-month (130-day) operation, using actual WW from the Rap-Shaw day to day operation.

After the start-up of the FBTS system as described in section 2.5., to establish a biofilm on the growth media the FBTS systems the recirculation flow was changed from 22.6 l/min (6 gal/min) to 40.0 l/min (10.6 gal/min) which increased the recirculation of the entire septic tank from 5.7 to 10.1 times a day.

The distributor made from a PVC pail having initial 20 holes arranged in the circumference and the bottom to equally distribute the WW flow were increased to 30 holes plus additional 10 holes on the side walls, 1-inch (24.4 mm) above the bottom, to accommodate the increased recirculation flow. The water level in the distributor was maintained at the original height of 8-inch (200 mm).

The operation of the FBTS system was kept as described in Section 2.2. and 2.5. for the duration of the test period.

To minimize contamination of the FBTS system with large organic and inorganic compounds from the kitchen effluents a filter is used in the kitchen sinks. In addition, all kitchen effluent has to pass through a grease trap, as shown in Figure 3., before it is discharged into the FBTS system.

3.1. Temperature and Rainfall during Operation

Figure 6., displays the average daily outside temperature and average daily rainfall during the 3-month (130-day) operation of the FBTS system. The temperature was at an average of 19.3°C (66.7°F) with a minimum average temperature between 14.0°C (57.2°F) and 22.6°C (76.2°F). The average daily rainfall was 5 l/m² with a maximum rainfall of 57 l/m² and 0 l/m² for days with no rain events.

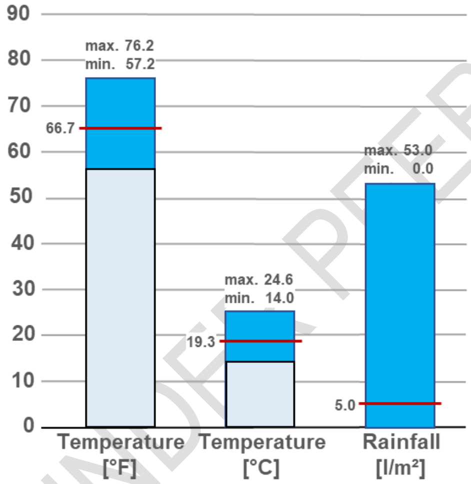

Fig. 6. Temperature and Rainfall

3.2. Water Usage

The water used at the camp is produced by a PW WTS system as described in Section 2.1., producing up to 9.2 gpm (34.8 l/min) for cooking, ice making, toilet and shower operation and daily use of guests. During the first half of the testing period the water meter was malfunctioning till it could be replaced in the second half of the testing period. During the second half of the testing period a total water usage of 3511 gal. (13,291 l) was measured. Therefore, it is safe to estimate that the overall camp operations water usage is about double at 7022 gal. (26,582 l).

Figure 7., shows the daily water usage for Breakfast, lunch and dinner. The water usage was between 4 gal (15.1 l) and 23 gal. (87.0 l) for the minimum and maximum with an average of

11 gal (41.6 l) for breakfast, a minimum of 4 gal (15.1 l) and a maximum of 22 gal. (82.3 l) with an average of 14 gal (53.0 l) for lunch, and a minimum of 4 gal (15.1 l) and a maximum 21 gal. (79.5 l) with an average of 8 gal (30.3 l) for dinner.

The average daily water usage was 54 gal (204.4 l) at a minimum and 160 gal. (605.6 l) at a maximum with an average of 90 gal (340.7 l).

Additional observation of water usage revealed that in the morning the main water usage was throughout the kitchen and very little fresh water was used by using the bathhouse. The water usage dropped during the day because most guests are involved in outside activities on-site or off-site the camp. During the evening time more water was used by using the bathhouse and showers. Based on the measured water usage, assuming that all used portable water is treated by the FBST, a Hydraulic retention Time (HRT) of the FBST during the 130-day test phase was on average 9.4 days for the maximum influent waterflow of 160 gal (605.6 l). For the minimum influent waterflow of 54 gal (204.4 l) the HRT was 27.7 days. The average retention time at the average water influent flow of 90 gal (340.7 l) during the test period was 16.7 days.

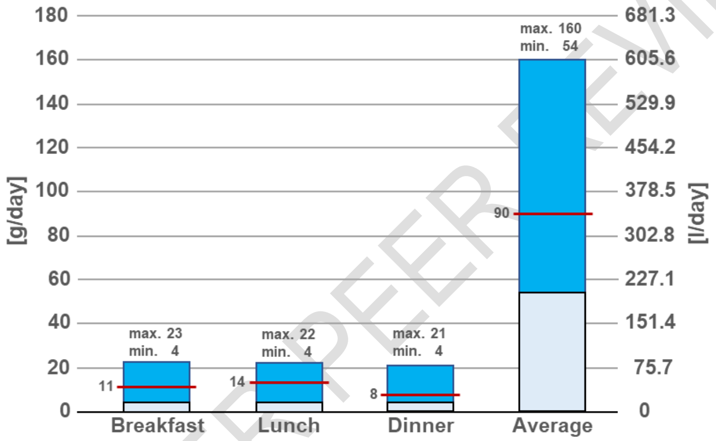

Fig. 7. Water Usage

3.3. Change of pH and Temperature

While operating the FBTS system with grey water the influent and effluent pH and temperature were measured during the 130-day trail period. The influent pH varied between 8.1 and 9.6 with an average of 8.6. The temperature for the influent was between 19.0°C and 25.5°C with an average temperature of 22.0°C. The effluent pH was measured between 7.5 and 9.7 with an average of 8.5. The measured effluent temperature was between 18.5°C and 24.9°C with an average temperature of 20.9°C. flowing into the septic tank, the pH kept stable for the influent and effluent. as shown in Figure 8., and slightly decrease from the influent pH might be related to the activity of acidifying bacteria in the reactor growing over time during the trial period. The slight decrease in temperature between influent and effluent can be explained by thermal losses. Temperature could also influence biological processes and many WW systems are operated at ambient conditions. However, WW influent temperatures fluctuated over the year. Average influent temperatures of WW systems can be based on own experience between 12°C and 23°C. Some systems might have higher fluctuations and can reach up to 35°C. Based on this our testing temperatures for the FBTS system stayed in the range communicated in the technical literature [34,35].

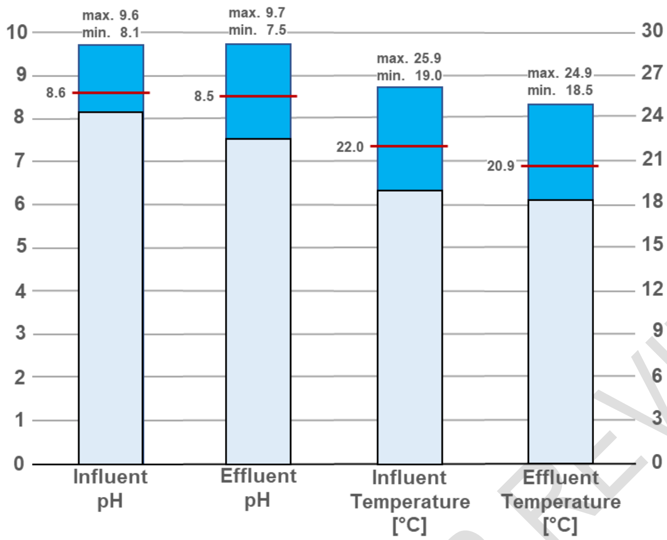

Fig. 8. Influent and Effluent pH and Temperature Field Bio-tower Septic System Installation.

3.4. Bio-tower Growth Media Biofilm

Figure 9. a) shows the BGMP without biofilm at the start of the project and Figure 5.b) shows the established biofilm after the end of the test period. The second section of the BGMP had a 2 to 3 mm thick biofilm established throughout the 34-inch (864 mm) height of the section. The first section with a height of 24-inch (610 mm) had a thick biofilm established only at the bottom 4 inch of the section. This is most likely due to the uneven water distribution of the first section, verifying that the first 20-inch are necessary for equal water distribution as described by the manufacturer of the BGMP [24].

Fig. 9. Bio-tower Growth Media Packaging a) with and b) without biofilm [36]

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3.5. Total Solids- and Total Suspended Solids Content

The TS and TDS influent and effluent values were measured as described in Section 2.5., and testing results are shown in Figure 10., at a minimum, maximum and average level for the 130-day testing period.

The TS content of the influent and effluent was measured at 206466 mg/l and 11299 mg/l for the influent and 191476 mg/l and 1996 mg/l at a maximum and minimum respectively. The TS for the influent and effluent was measured with an average TS of 79151 mg/l and 43021 mg/l respectively.

The TDS values of the influent and effluent was measured by filtering the influent and effluent samples with a 45 µm pore size glass fiber fabric filter (HACH, Be Right, grade: MGA, 47 mm), followed by the in section 2.5., described testing procedure for the TS.

The TDS content of the influent was measured at 55963 mg/l and 3858 mg/l for the maximum and minimum respectively, with an average TS of 36426 mg/l. The effluent TDS measurement gave values of 37953 mg/l for the maximum and 1829 mg/l for the minimum. The average TDS for the effluent was measured at 21965 mg/l.

Maximum levels of TS and TDS were measured mostly during the morning testing were minimum level showed mostly during the evening testing, because the ww influent is mostly diluted with less contaminated WW from the bathhouse.

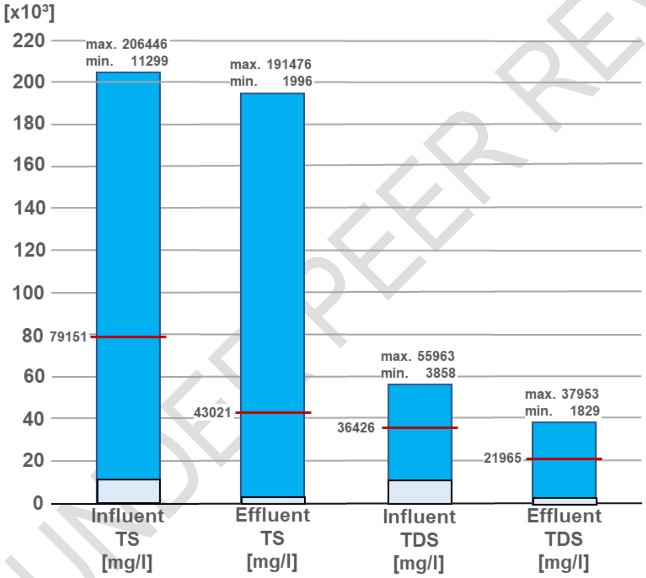

Fig. 10. Influent and Effluent Total Solids- and Total Dissolved Solids Content

3.6. Total Suspended-, Volatile Suspended-, and Fixed Suspended Solids Content

The TSS, VSS, and FSS influent and effluent values were measured as described in Section 2.5., with testing results, shown in Figure 11., at a minimum, maximum and average level for the 130-day testing period.

The TSS content of the influent and effluent was measured at 278.9 mg/l and 48.7 mg/l for the influent and 136.5 mg/l and 37.6 mg/l at a maximum and minimum respectively. The TS for the influent and effluent was measured with an average TSS of 94.1 mg/l and 69.9 mg/l respectively.

The VSS values of the influent and effluent was measured by filtering the influent and effluent samples with a 45 µm pore size glass fiber fabric filter (HACH, Be Right, grade: MGA, 47 mm), and igniting the TS content remaining on the glass fiber fabric filter pad in ceramic crucibles at 525°C, following the in section 2.5., described testing procedure for the VSS.

The VSS content of the influent was measured at 204.1 mg/l and 42.8 mg/l for the maximum and minimum respectively, with an average TSS of 89.0 mg/l. The effluent TSS measurement gave values of 129.2 mg/l for the maximum and 32.2 mg/l for the minimum. The average TDS for the effluent was measured at 64.9 mg/l.

Inorganic particles that made it through the 45 µm pore size glass fiber fabric filter pad of the filtered influent and effluent for determining by subtracting the VSS value from the TSS value.

The FSS content of the influent was measured at 26.4 mg/l and 1.2 mg/l for the maximum and minimum respectively, with an average TSS of 6.5 mg/l. The effluent FSS measurement gave values of 20.4 mg/l for the maximum and 0.6 mg/l for the minimum. The average FSS for the effluent was measured at 6.0 mg/l.

Maximum levels of TSS, VSS and FSS were measured mostly during the morning testing were minimum levels showed mostly during the evening testing, because the WW influent is mostly diluted with less contaminated WW from the bathhouse.

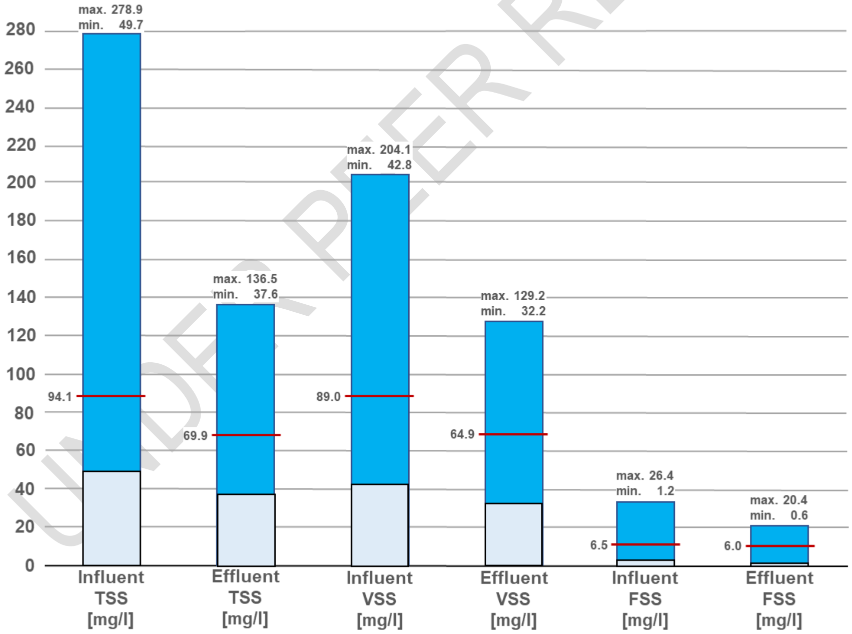

Fig. 11. Influent and Effluent Total Suspended, Volatile Suspended, and Fixed Suspended Solids Content

3.7. Nitrogen Ammonia and Phosphor Content

Nitrogen Ammonia (NH_3-N) and Total Phosphorus as PO_4 was measured according to the in Section 2.4. described HACH testing methods. Figure 12., displays the minimum, maximum and average NH_3-N and PO_4 values during the 130-day testing period.

The NH_3-N content of the influent was measured at 100.0 mg/l and 20.1 mg/l for the maximum and minimum respectively, with an average NH_3-N of 57.5 mg/l. The effluent NH_3-N measurement gave values of 80.0 mg/l for the maximum and 21.0 mg/l for the minimum. The average NH_3-N for the effluent was measured at 53.4 mg/l.

Total PO_4 of the influent was measured at 24.8 mg/l and 3.3 mg/l for the maximum and minimum respectively, with an average PO_4 of 16.8 mg/l. The effluent PO_4 measurement gave values of 39.0 mg/l for the maximum and 13.0 mg/l for the minimum. The average PO_4 for the effluent was measured at 22.1 mg/l.

Maximum NH_3-N were measured mostly during the morning testing were minimum levels showed mostly during the evening testing, because the WW influent is mostly diluted with less contaminated WW from the bathhouse.

For the PO_4 Testing an increase over the testing time was noticed, indicating that PO_4 Must accumulate in the FBTS system. In addition, a higher was noticed if poultry food was served. A publication by XYZ indicates the same findings…….

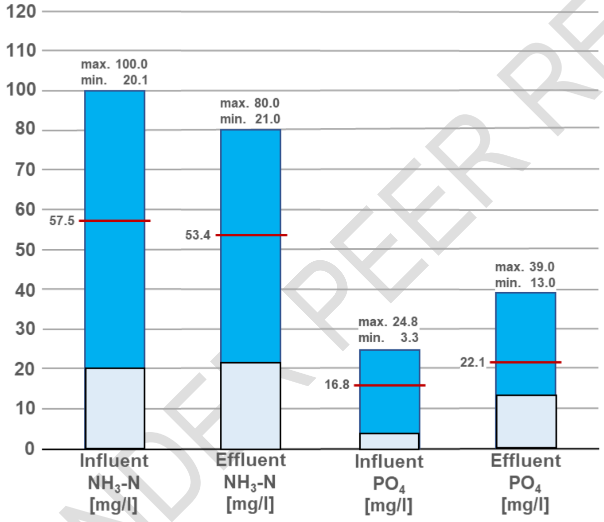

Fig. 12. Influent and Effluent Nitrogen Ammonia and Phosphor Content

3.8. Biohemical Oxygen Demand and chemical Oxygen Demand

COD was measured according to the in Section 2.4. described HACH testing methods. The BOD was calculated by establishing a BOD ratio between COD and BOD using certified laboratory testing. The established ratio between BOD and COD was 3.61.

Figure 13., below shoe the measured BOD and COD values during the 130-day testing period.

The BOD content of the influent was measured at 331.6 mg/l and 20.5 mg/l for the maximum and minimum respectively, with an average BOD of 88.2 mg/l. The effluent BOD measurement gave values of 128.6 mg/l for the maximum and 15.5 mg/l for the minimum. The average BOD for the effluent was measured at 68.8 mg/l.

Total COD of the influent was measured at 1196 mg/l and 81.0 mg/l for the maximum and minimum respectively, with an average PO_4 of 318.2 mg/l. The effluent COD measurement gave values of 464.0 mg/l for the maximum and 56.0 mg/l for the minimum. The average BOD for the effluent was measured at 255.2 mg/l.

Maximum BOD and COD were measured mostly during the morning testing were minimum levels showed mostly during the evening testing, because the WW influent is mostly diluted with less contaminated WW from the bathhouse. The lowest BOD and COD values of 15.5 mg/l and 56.0 mg/l respectively were observed at the end of the testing period were bacteria cultures are well established and the system operation of the FBTS system is mostly constant, showing that the addition of a bio-tower to a septic system can significantly improve its performance reducing the influent values of the WW of up to 10 times, and achieving discharge values close to commercial waste water treatment plants [34, 37].

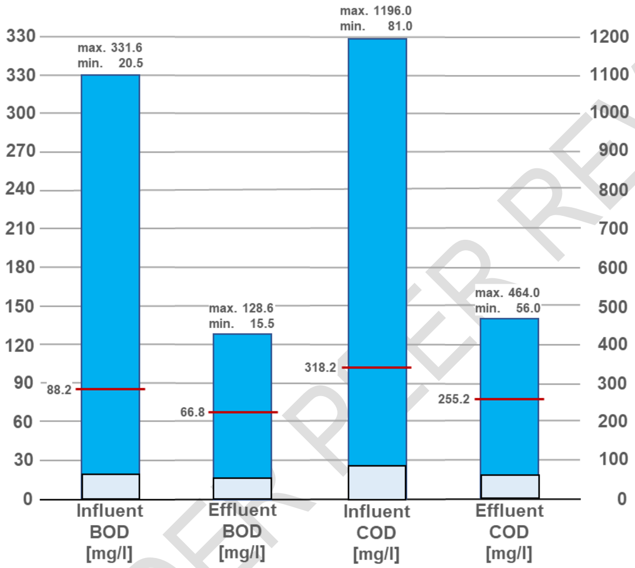

Fig. 13. Influent and Effluent BOD Nitrogen Ammonia and Phosphor Content

3.9. Oxygen Reduction Potential

ORP determines the ability to break down organic components in the liquid, whereas a high OPR indicates that more oxygen is present as for lower ORP numbers. The ORP values, shown in Figure 14., were measured according with a Hanna OPR meter.

The ORP values of the influent was measured at 247.1 mA and -196.2 mA for the maximum and minimum respectively, with an average ORP of -26.5 mA. The effluent ORP measurement gave values of 81.6 mA for the maximum and -135.0 mA for the minimum. The average ORP for the effluent was measured at -24.3 mA

The lowest ORP values were observed at the end of the testing period where bacteria cultures are well established and the system operation of the FBTS system is mostly constant. This shows that the addition of a bio-tower can enhance the performance septic system by adding more oxygen into the system and over time increase the bacteria numbers in the system increasing its ability to degrade the organic content in the wastewater.

Monitoring the ORP can help to adjust and monitor the performance of an FBTS system.

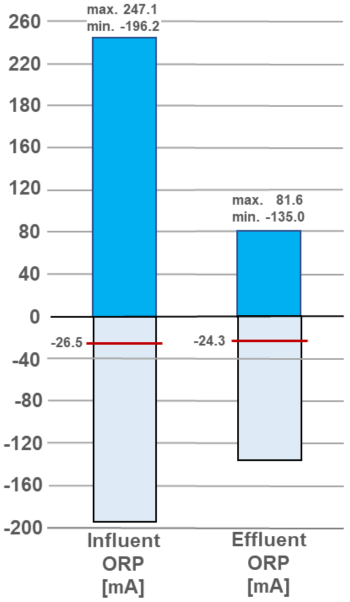

Fig. 14. Influent and Effluent ORP Value

3.10. Additional Operation Results

During the 130-day test period it showed that the pump performance of the 0.186 kW (0.25 hp) Thermoplastic Submersible Utility Pump from Superior Pump Model 91250 is very dependent on influent WW load of the FBTS system, requiring periodical cleaning of the filtration grid on the impeller influent side. For example, fibrous food such as fibrous vegetables and corn products require more cleaning due to the inability of the human body to fully digest these food items. Thes unprocessed food products plug the influent grid of the pump.

At the beginning of the study, it was noted that the performance of the FBTS increases without the use of hygienic toilet liquids and products. Therefore, the use of these products had been eliminated for the septic system.

3.11. Suggestions for Further Research

During the 130-day test period it showed that the pump performance of the 0.186 kW (0.25 hp) Thermoplastic Submersible Utility Pump from Superior Pump Model 91250 is very dependent on the influent WW condition. Therefore, it is suggested to use a commercial grinder pump.

Future research should focus if different recirculation rates have an increasing or decreasing effect on the TS, TSS, BOD and COD value of the effluent as well as if locating the bio-tower after the septic tank can increase the system performance and decrease the size of the bio-tower and the system overall.

CONCLUSION

Sustaining natural beauty of suburban and rural waterbodies and environments is one of today’s a big challenge. DWWTS have been employed to minimize water pollution, because WWTP are too far away. Underperforming DWWTS can contribute to the pollution of nearby water bodies, causing nitrification and an increase in phosphorus components. This could increase algae growth mostly during warm summer month with negative effects on the environment, public health and the economy.

A FBST system was designed, installed on an existing 1,500-gal (5678 l) DWWTS and started up during a 14-day start-up phase, followed by a 130-day test operation. The FBST was then operated at an average HRT of 16.7 days based on a 90 gal (204.4 l) daily influent WW flow.

The FBTS systems recirculation flow for the bio-tower was 22.6 l/min (6 gal/min) for the start-up phase and 40.0 l/min (10.6 gal/min) for the test period with a corresponding recirculation of the entire septic tank from 5.7 to 10.1 times a day respectively.

During the testing period an daily average temperature of 19.3°C (66.7°F) and an average rainfall of 5 l/m² was observed. The FBST system operated at an average influent pH level and temperature of 8.6 and 22.0°C. The average effluent pH and temperature was 8.5 of 20.9°C.

The FBST system reduced on average the influent TS from 79151 mg/l to 43021 mg/l and shoed an average reduction of the TDS from 36424 mg/l to 21965 mf/l. The TSS and VSS was reduced on average from 94.1 mg/l to 69.9 mg/l and 89.0 mg/l to 64.9 mg/l.

NH_3-N content was reduced from 57.5 mg/l in the influent to 53.4 mg/l in the effluent. The average BOD and COD was reduced from the average influent value of 88.2 mg/l and 318.2 mg/l to 66.8 mg/l and 256.2 mg/l respectively. However, at the end of the 130-day test period BOD and COD values were the lowest at 15.5 mg/l and 56.0 mg/l respectively, indicating bacteria cultures are well established and the system operation of the FBTS system is mostly constant.

This research showed that the FBST system can improve operations of a DWWTS system significantly reducing the effluent load over 10 times compared to the influent load of the system.

Based on this research future research should focus if different recirculation rates have an increasing or decreasing effect on the TS, TSS, BOD and COD value of the effluent as well as if locating the bio-tower after the septic tank can increase the system performance and bio-tower size needed.

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